Phase IV:
Final Project Report

San Luis Obispo Creek
Total Maximum Daily Load
For
Nutrients

State of California
Central Coast Regional Water Quality Control Board

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1 Introduction and Problem Statement

This document addresses the 303(d) listing for San Luis Obispo Creek. San Luis Obispo Creek (Creek) was placed on the 303(d) list of impaired waterbodies in 1994; the Creek was listed as impaired by nutrients.

The basis for the 303(d) listing is not well documented, as were many of the early listings. As such, the impairment associated with the listing was not articulated at the time of placement on the 303(d) list. However, the impairment is a vital component of TMDL development as the TMDL must include a plan to correct the impairment associated with the listing. Therefore, the following subsection summarizes the events leading to the 303(d) listing, supporting a conclusion of the intended impairment associated with the listing.

1.1 Background of Listing

In 1990, San Luis Obispo Creek was on two lists, 304(l) and 131.11, that identify impaired waters. The impaired waters list required by Section 304(l) of the Clean Water Act identifies water bodies that do not achieve applicable water quality standards due to toxic pollutants from point sources, even after application of technology-based measures have been utilized. Section 131.11 of 40 CFR required states to list specific water bodies where toxic pollutants adversely affect attainment of designated uses.

The Creek was placed on the 304(l) and 131.11 lists for the reasons stated below:

1. Threat of drinking water impairment.
2. Fish population decline.

The threat of drinking water impairment referred to exceedence of the nitrate water quality objective protecting the municipal drinking water beneficial use. The nitrate water quality objective was in 1990, and still is today, 10.0 mg/L-N. Nitrate concentration data was available through monitoring reports submitted by the city of San Luis Obispo’s wastewater treatment plant, known as the Water Reclamation Facility (WRF). Data from the WRF monitoring reports were used as the basis of determination that the drinking water use was being threatened.

The fish population decline was attributed to historic ammonia concentrations present at toxic levels in the Creek that were driven by the ammonia-rich effluent from the WRF. In 1994, the WRF completed and put on line a technological upgrade that significantly reduced the ammonia discharge to non-toxic levels consistent with Basin Plan water quality objectives. Data gathered (after the plant upgrade) by the WRF from monitoring efforts required through the WRFs NPDES permit, confirms that ammonia levels are no longer in exceedence of Basin Plan objectives (this point will be elaborated on in sections that below).

In 1992, the Creek was placed on the CWA Section 319 list. The 319 list identifies water bodies which, without additional control of nonpoint sources of pollution, cannot reasonably be expected to attain water quality objectives. The reasons stated for placement of the Creek on the 319 list are the same reasons listed for placement on the 304(l) and 131.11 lists, as stated in bullets 1 and 2 above.

The 303(d) list is a list of impaired waters that do not meet water quality standards even after point source dischargers of pollution have applied the minimum required efforts of pollution control technology. Note that the criteria for the 303(d) list are very similar to the criteria for the 304(l) list.

The State Water Resources Control Board made the decision that the criteria for the 304(l) list were similar enough to criteria of the 303(d) list that all water bodies on the 304(l) list were to be placed on the 303(d) list. It is subsequent to this decision that San Luis Obispo Creek was placed on the 303(d) list. Staff employed at the Central Coast Regional Board during this period have concurred that water bodies on the 304(l) list were automatically placed on the 303(d) list. Veteran staff have also added that once a water body was placed on the 303(d) list, removal from the list was strongly discouraged by EPA, who had the ultimate authority to do so, even if it was later found that evidence supporting impairment was insufficient.

In 1994, San Luis Obispo Creek was placed on the 303(d) list. The Creek was listed as impaired for "nutrients." There was no accompanying data supporting the listing. The listing, however, articulates that the source was "municipal." Please note that the municipal source is the WRF, and recall from the discussion above that data from the WRF is believed to have prompted placement of the Creek on the 304(l) list for threat of drinking water impairment.

Given the information leading to the 303(d) listing of the Creek, staff concludes that San Luis Obispo Creek was placed on the 303(d) list as a result of being rolled over from the 304(l) list, which was prompted by nitrate and ammonia values reported in the WRF monitoring reports. As such, the listing intended to address impairments to drinking water supply and fish population decline, driven by nitrate and unionized ammonia concentrations, respectively.

1.2 Potential Impairments Due to Nutrients

The impairment leading to the 303(d) listing was due to threat to drinking water and fish population decline, driven by nitrate and ammonia, respectively. However, staff have investigated other impairments that could be driven by nutrient enrichment. Using existing Basin Plan water quality objectives as a determination of potential impairment, staff have formulated three categories of impairment related to nutrient enrichment. The categories are briefly discussed in the following three subsections, which support the finding articulated in the Problem Statement.

1.2.1 Threat to Drinking Water

The municipal water supply beneficial use (MUN) is in part protected by the nitrate water quality objective. The water quality objective for nitrate is 10 mg/L-N. Therefore, nitrate concentrations exceeding 10 mg/L-N in the Creek implies that the MUN beneficial use is not being protected, and therefore would be a reason for impairment due to nitrate.

1.2.2 Threat of Toxicity

The threat of toxicity to aquatic organisms is in part protected by the unionized ammonia water quality objective. The water quality objective for unionized ammonia is stated as follows:

"The discharge of wastes shall not cause concentration of unionized ammonia (NH_3) to exceed 0.025 mg/L (as N) in receiving waters."

Therefore, unionized ammonia concentration exceeding 0.025 mg/L-N in receiving waters indicates impairment due to toxicity.

1.2.3 Impairments from Aquatic Growths and Biostimulatory Substances

The negative affect to beneficial uses from aquatic plant growths is a common and sometimes logical consideration when addressing impacts due to nutrients. Types of aquatic growths often considered are benthic algae, suspended algae, and other aquatic plants that may have adverse impacts to beneficial uses. The potential for negative impacts from aquatic growths is reflected in the Water Quality Control Plan (Basin Plan) through the narrative biostimulatory substances water quality objective, which states:

"Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses."

Note in the narrative objective the key phrase (with respect to impairment) that growths shall not cause nuisance or adversely affect beneficial uses. The Basin Plan does not define nuisance or adverse affects from aquatic growths to beneficial uses either generally, or with respect to specific beneficial uses. As such, in order to associate aquatic growths to water quality impairment, the relationship between aquatic growths and individual beneficial uses must first be established, i.e., the growth threashold level (or similar) at which a beneficial use is impaired must be established. In order to do so, a method of analysis with which to measure aquatic growths must also be established; e.g., the number plots along a linear length of stream that must exceed the threashold level for impairment to occur.

In short, the biostimulatory substances objective must be revisited and clearly defined with respect to individual beneficial uses. Without such clarification, impairment can neither be defined nor addressed in such a way as to eliminate the impairment because there exists no criteria with which to gauge the impairment or verify when non-impairment is achieved. Therefore, to incorporate potential adverse impacts from biostimulation in the TMDL and implementation, the existing biostimulation objective must first be re-evaluated and perhaps revised. Revisions to current water quality objectives require a Basin Plan amendment separate from the TMDL.

The lack of clarity of the biostimulatory substances objective in the Central Coast Region Basin Plan, as well as Basin Plans of other Regional Boards, is well known and discussed among staff. Nutrient TMDL efforts in California, as well as other states, are driving efforts to clarify how aquatic growths impact aquatic systems. Efforts include:

- Regional Technical Advisory Group (RTAG). The RTAG is an EPA Region IX effort to establish nutrient criteria or a protocol for developing nutrient criteria. Results of this effort will be applicable to the state of California.

- Tetra-Tech is a consulting firm contracted by the SWRCB to develop and suggest means for applying the biostimulation objective with respect to nutrients. Tetra-Tech will research and report definitions of nuisance algal levels as they pertain to stream systems and make recommendations regarding nutrient levels aimed at avoiding such nuisance levels.
- Staff from Water quality Control Boards continue to compile information and data with respect to nutrient related impairments in an effort to develop nutrient numeric targets protective of all beneficial uses. In addition, staff are making efforts to acquire the resources necessary (separate from TMDL resources) to research how aquatic growths affect beneficial uses with the ultimate objective of revising biostimulatory and related water quality objectives.

1.3 Basis of TMDL Development

The facts set forth in the above sections lead staff to consider several options regarding how the TMDL can be developed. The key question is whether the biostimulatory objective can be utilized to state and justify impairment due to biostimulation. Three option categories and associated pros/cons are considered:

1. Address potential impairments due to nitrate (threat to drinking water) and ammonia (threat of toxicity) and develop a TMDL based on the existing water quality objectives for these two constituents. Concurrently, monitor and take part in the current efforts to clarify the biostimulatory objective and apply the results to San Luis Obispo Creek, i.e., determine whether the Creek is impaired due to biostimulation and implement methods for rectifying the impairment after methods have been established in a separate TMDL.
    a. Advantages:
        i. Existing nitrate and ammonia water quality objectives would be adressed and the beneficial uses these objectives protect would be protected upon achievement of the TMDL.
        ii. The existing nitrate and ammonia water quality objectives are clear. The resulting TMDL, allocations, and implementation strategy would be scientifically valid and defensible.
        iii. Addressing potential biostimulation problems at a latter date would help avoid errors that could be made by implementing strategies that have not been scientifically validated.
    b. Disadvantages:
        i. The potential adverse impacts to beneficial uses from aquatic growths would not be addressed in this TMDL. Any adverse impacts currently existing would continue.

2. Use limited available data to conclude that the Creek is impaired from biostimulation. Implement the TMDL through regulation by applying literature values for nutrients to control aquatic growths.
    a. Advantages:
        i. Potential adverse affects to beneficial uses from aquatic growths would be addressed, although not rectified (see disadvantages).
        ii. The impairment to the drinking water (from nitrate) and toxicity (from ammonia) would be rectified (this is so because it is widely understood that nitrate levels needed to control aquatic growths are lower than the nitrate objective to protect drinking water).

b. Disadvantages:
    i. Literature values aimed at minimizing aquatic growths are an order of magnitude lower than is technologically possible to achieve by identified point dischargers discharging to San Luis Obispo Creek. Therefore, the TMDL, if based on literature values, would not be achieved and aquatic growths would not be reduced to intended levels. In addition, identified dischargers would be subject to mandatory penalties for not achieving mandated effluent limits, even after utilizing millions of tax dollars to achieve nutrient levels achievable through best available technology, yet not lower than literature values aimed at reducing aquatic growths.
    ii. As discussed in the previous section, the thresholds and methods needed to confirm impairment and develop a TMDL aimed at eliminating adverse affects from biostimulation have not been formulated. The scientific basis needed to develop a TMDL would therefore be absent. As a result, implementation resulting in regulation of existing identified dischargers would be unfounded, scientifically unjustified, and subject to intense scrutiny.

3. Delay TMDL development until scientific investigation results in refinement of the biostimulation objective, and then complete the TMDL after findings have been translated into promulgated water quality objectives.
    a. Advantages:
        i. Any water quality impairments that do exist due to aquatic growths could potentially be rectified in the future.
        ii. The impairment to the drinking water beneficial use would be rectified when the TMDL is implemented (this is so because it is widely understood that nitrate levels needed to control aquatic growths are lower than the nitrate objective to protect drinking water).
    b. Disadvantages:
        i. TMDL development would be delayed for an unknown period of time. As a result, identified impairments would continue.
        ii. If refinement of the biostimulatory objective lead to the conclusion that San Luis Obispo Creek is not impaired from aquatic growths, there would be no advantage to delaying TMDL development; i.e., exercising this option would gain nothing for water quality, but would only delay the rectification of the identified impairment (e.g. due to threat to drinking water).

Based on the advantages and disadvantages presented above, staff are confident that the first option represents the option that maximizes benefits and efficiency to water quality and resource utilization. In addition, recall from Section 1.1 that the listing was likely based on impairment from nitrate and ammonia and their threat to drinking water and aquatic toxicity, respectively. Therefore, the following TMDL will address exceedence of the existing nitrate and unionized ammonia water quality objectives. A separate listing associated with aquatic growths will be considered after the biostimulation objective has been clarified and scientific methods associated with biostimulation have been established.

1.4 San Luis Obispo Creek Watershed and Setting

The San Luis Obispo Creek Watershed (the Watershed) is located on the Central Coast of California, approximately 240 miles south of San Francisco and 200 miles north of Los Angeles, as shown in Figure 1.1, below. The Watershed encompasses 219 km^2 (84.6 mi^2, 54,142 acres), and is home to the 44,000 residents of the city of San Luis Obispo (City). The City encompasses 23 km^2 (9 mi^2), and lies nearly in the middle of the watershed, with San Luis Obispo Creek (Creek) flowing through the downtown area.

The main stem of the Creek is approximately 27.4 kilometers in length (17 miles). The headwaters flow from an elevation of 518 meters (1700 feet) to the mouth at Avila Bay at the Pacific Ocean. Eleven tributaries contribute flow to the Creek, including:

- Brizziolari Creek
- Davenport Creek
- East Fork
- Froom Creek
- Old Garden Creek
- Prefumo Creek
- Reservoir Canyon Creek
- San Miguelito Creek
- Squire Canyon Creek
- Stenner Creek
- Sycamore Creek.

In addition, the damming of Prefumo Creek has created Laguna Lake, which provides recreation for local residents as well as habitat for wildlife. Figure 1.2 illustrates the Watershed and its tributaries.

Climate in the watershed is Mediterranean, experiencing cool wet winters with relatively warm dry summers. Average monthly temperatures from 1950 to 1999 ranged from 41.6 F° in January to 79.2 F° in September. Annual rainfall for the same period of record ranged from 27.7 cm to 105.8 cm. (10.91 to 41.67 in).

Average monthly flow near the mouth of the Creek ranges from 0.16 m^3/sec in September to 3.6 m^3/sec in March (5.8 ft^3/sec to 127.2 ft^3/sec) for the period of record from 1971 to 1986. The City operates and presently discharges approximately 4000 acre-feet of disinfected tertiary reclaimed municipal wastewater, accounting for an average of 0.156 m^3/sec (5.5 ft^3/sec) of flow in the Creek. Therefore, the Creek may be effluent dominated in the lower 11 km (7 miles) during some months of the year.

Figure 1.1 Location of San Luis Obispo Cr. Watershed

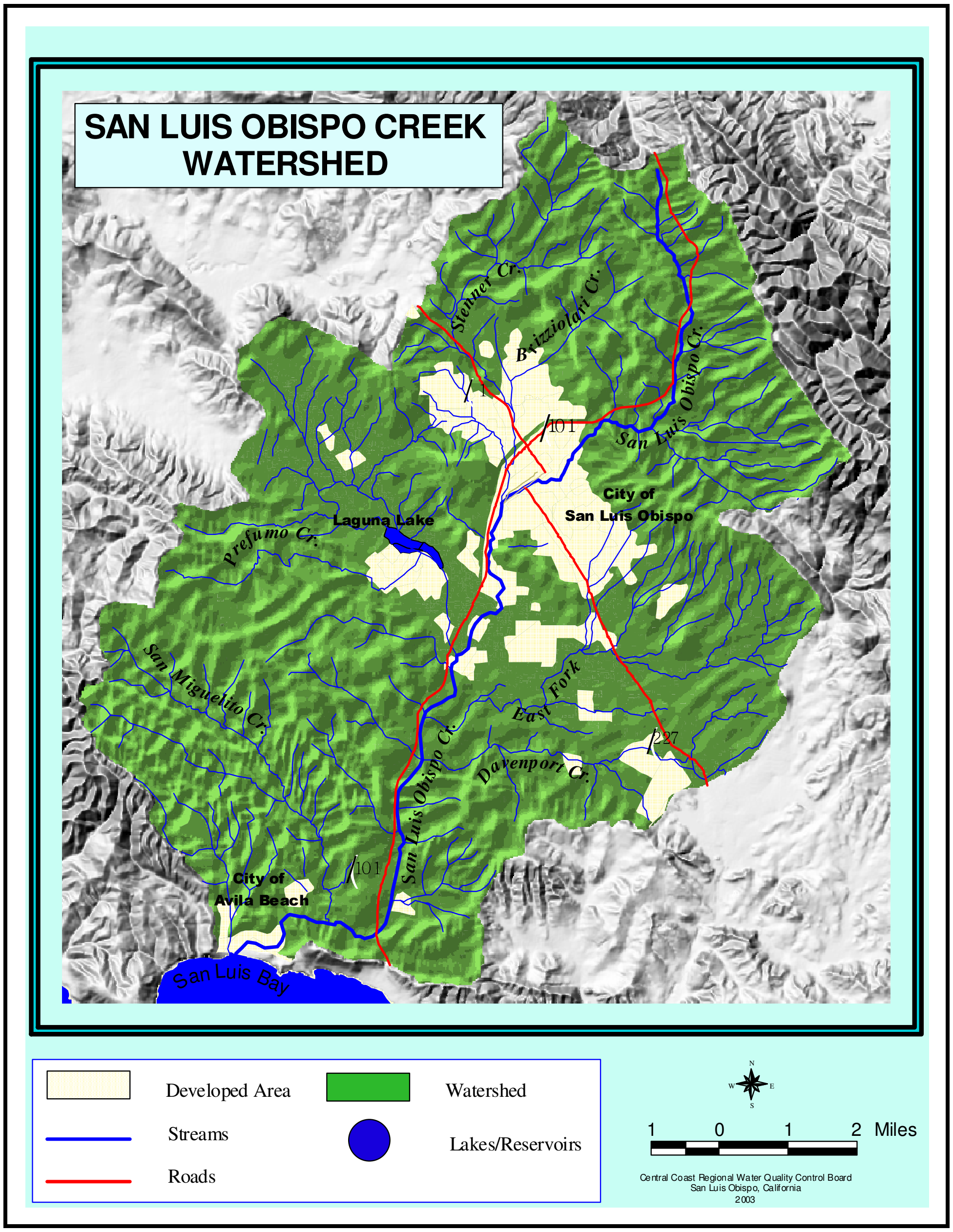

Figure 1.2 San Luis Obispo Creek Watershed

1.5 Beneficial Uses and Water Quality Objectives

The Water Quality Control Plan for the Central Coast Region (Basin Plan) identifies the following thirteen beneficial uses of the Creek and its tributaries.

- Municipal and Domestic Water Supply (MUN)
- Agricultural Supply (AGR)
- Ground Water Recharge (GWR)
- Water Contact Recreation (REC-1)
- Non-Contact Water Recreation (REC-2)
- Wildlife Habitat (WILD)
- Cold Freshwater Habitat (COLD)
- Warm Freshwater Habitat (WARM)
- Migration of Aquatic Organisms (MIGR)
- Spawning, Reproduction, and/or Early Developments (SPWN)
- Rare, Threatened, or Endangered Species (RARE)
- Freshwater Replenishment (FRSH)
- Commercial and Sport Fishing (COMM)

In addition to the beneficial uses above, the Creek is also designated to support the beneficial uses of Shellfish harvesting (SHELL) and Aquaculture (AQUA) near the mouth of the system.

1.6 Data Supporting Impairment and Problem Statement

1.6.1 Nitrate and the Municipal Water Supply Beneficial Use

The entire main stem of the Creek is designated to support the municipal water supply (MUN) beneficial use. The MUN beneficial use is in part protected by a numeric objective for nitrate. The basin plan water quality objective for nitrate is 10 mg/L-N.

Data collected by staff clearly indicate that nitrate levels in the Creek exceed the 10 mg/L-N threashold, particularly downstream of the WRF discharge. The figure below illustrates nitrate levels along the main stem of the Creek, each diamond represents a nitrate concentration.

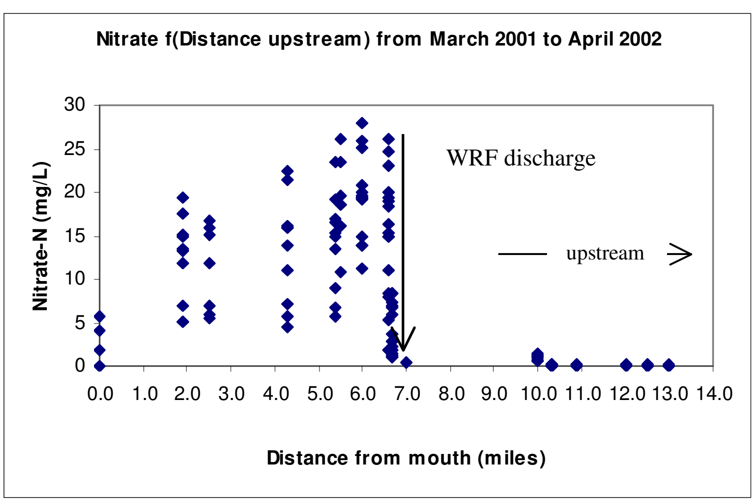

Figure 1.3 Nitrate Concentrations Along Main Stem

Note from Figure 1.3 above that nitrate levels are consistently above the 10 mg/L-N objective in the lower portion of the watershed. Specifically, nitrate levels are above the Basin Plan objective downstream of site 7.0, corresponding to the WRF discharge point.

1.6.2 Unionized Ammonia Water Quality Objective

The unionized ammonia objective states that the discharge of wastes cannot cause unionized ammonia concentration to exceed 0.025 mg/L-N.

The WRF discharges treated waste water into the Creek. In 1994 the WRF completed and put online a technological upgrade resulting in a significant reduction of unionized ammonia in the effluent. The upgrade was completed specifically to address ammonia discharge with the intent to achieve the unionized ammonia objective.

The WRF is required to monitor and report various constituent concentrations in their influent, effluent, and receiving water. Specifically, unionized ammonia concentration is determined weekly both upstream and downstream of the discharge point in an effort to verify non-exceedence of the ammonia objective. Unionized ammonia data is summarized for the period of record from February 2000 to April 2001 in the table below.

Table 1.1 Exceedences of Unionized Ammonia Objective from WRF

Monitoring Site[1]	No. of Non-detects[2]	No. of Exceedences[3]	% Exceedences of Total[4]
Upstream of Discharge	103	0	0
Downstream of Discharge	98	9	8%

1 Upstream and downstream of WRF discharge.
2 Of the samples drawn, number of samples where ammonia was non-detected (<0.01 mg/LN).
3 Number of exceedences of the unionized ammonia objective.
4 Number of unionized ammonia exceedences expressed as the percent of total samples drawn.

Note that eight exceedences occurred downstream of the discharge point. All eight exceedences occurred within a 68-day period from August 2001 to October 2001. The exceedences were due to an illegal discharge, by an unknown party, of solvent into the sewer system. The discharge was well documented at the time. The WRF attempted unsuccessfully to locate the source of the discharge. The illegal discharge of solvent created an upset in the biologically dependent treatment, resulting in the eight exceedences. The illegal spill ceased, and subsequent data suggest that unionized ammonia levels in the receiving water meets the unionized ammonia objective.

Also note that the 8 exceedences represent 8% of the total samples taken downstream of the discharge point for the period of record. Eight percent exceedence of the unionized ammonia objective does not constitute impairment; based on recent listing discussions that assume 10% exceedence constitutes impairment. In addition, no fish kills or other organism mortality was reported.

Given the information presented above, staff conclude that the Creek is not impaired for unionized ammonia. In short, the ammonia concentrations used, in part, as a basis for the listing was specifically addressed by the WRF plant upgrade, resulting in attainment of the water quality objective for unionized ammonia.

1.7 Problem Statement

Upon consideration of the information outlined above, staff have determined that one beneficial use is not being protected in San Luis Obispo Creek due to nutrients. Specifically, the municipal water supply beneficial use is not being protected due to exceedence of the water quality objective for nitrate. The water quality objective for nitrate is 10 mg/L-N, which is exceeded in the lower reaches of the watershed, corresponding to flows downstream of monitoring site 7.0, which is located approximately 7 miles upstream from the mouth of the Creek.

Consequently, a source analysis and corresponding TMDL is developed herein with the objective of achieving the nitrate water quality objective, and subsequent protection of the municipal water supply beneficial use.

2 Numeric Targets

The numeric target used to calculate the TMDL and subsequent allocations is consistent with the water quality objective for the protection of the municipal water supply beneficial use. A discussion supporting the target is provided in the former section.

The numeric target used to calculate the TMDL is a nitrate target of 10 mg/L-N.

3 Source Analysis

3.1 Introduction

The Source Analysis will:

1. Identify sources of nitrate to the Creek.
2. Categorize the identified sources.
3. Identify the relative contributions of nitrate by source.

The flowchart in Figure 3.1 briefly outlines the source analysis process.

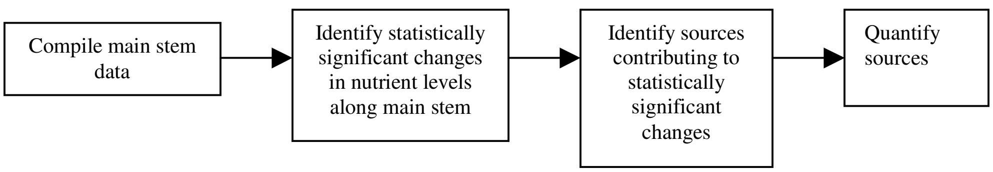

Figure 3.1 Source analysis flowchart

3.2 Methods

3.2.1 Data

Staff utilized two sources of data: 1) data from creek monitoring conducted by staff, and 2) data collected by the City in accordance with the Monitoring and Reporting Program under their NPDES Water Reclamation Facility permit.

3.2.1.1 Spreadsheet Data and Calculations

The TMDL is the result of hundreds of calculations utilizing multiple data points. Key calculations and data summaries in this document will reference the spreadsheet accompanying this document.

3.2.2 Creek Monitoring

Staff began a Creek monitoring program in March 2001. Forty-one sites throughout the watershed, including 15 along the main stem of the Creek, were used to collect over 500 data. Water column data were analyzed for nitrate (NO_3), nitrite, total ammonia, total nitrogen, orthophosphate, and total phosphorus. A limited number of in-situ data were also collected for chlorophyll-a, dissolved oxygen, temperature, and canopy. Sampling procedures, holding times, and transportation protocol followed methods as outlined in Standard Methods (Greenberg *et al*, 1992).

Flow measurements were accomplished using two methods: 1) area/surface velocity method, and 2) Pygmy flow meter. In the area/surface velocity method, velocity was determined at the stream surface by allowing a stick to float a measured distance. Areas at cross-sections were determined by first determining the geometry of the cross-section. Cross-section geometry was noted as rectangular, triangular, or trapezoidal, and the area calculated. Discharge was then calculated using: $Q = AV$, where Q is discharge, A is area, and V is velocity. Linear measurements were accomplished with a 100-meter cloth tape, or, in the case of small-width channel sections, with a measuring rod with 0.1-foot graduations. Channel depth was accomplished with the measuring rod as well. Flow measurements were also made using a Pygmy Flow meter Model 6205. The flow meter became available to staff in November 2001.

Table 3.1 lists the methods used by the laboratory, as well as instruments used by Staff for *in situ* creek monitoring.

Table 3.1 Methods and instruments for creek monitoring.

Constituent	Method	Reporting Limit
Nitrite	EPA 300.0	0.1 mg/L
Nitrate	EPA 300.0	0.1 mg/L
Total Ammonia	SM 4500 NH3-F	0.02 mg/L
Total Kjeldahl Nitrogen	EPA 351.3	0.5 mg/L
Ortho Phosphorous	EPA 365.1	0.01 mg/L
Total Phosphorous	EPA 365.1	0.02 mg/L
Chlorophyll-a	(*In situ*) Hydrolab 4a	
Dissolved Oxygen	(*In situ*) YSI 95	
Temperature	(*In situ*) YSI 95	
Canopy	(*In situ*) Spherical Densiometer, Model C	
Flow	USGS Pygmy current meter	

Monitoring sites were established upstream and downstream of major tributaries, as well as up and downstream from known and suspected sources. Sites were also established at locations designed to reflect background nutrient levels. Figures 3.2 and 3.3 below illustrate the monitoring sites along the main stem and tributaries, respectively.

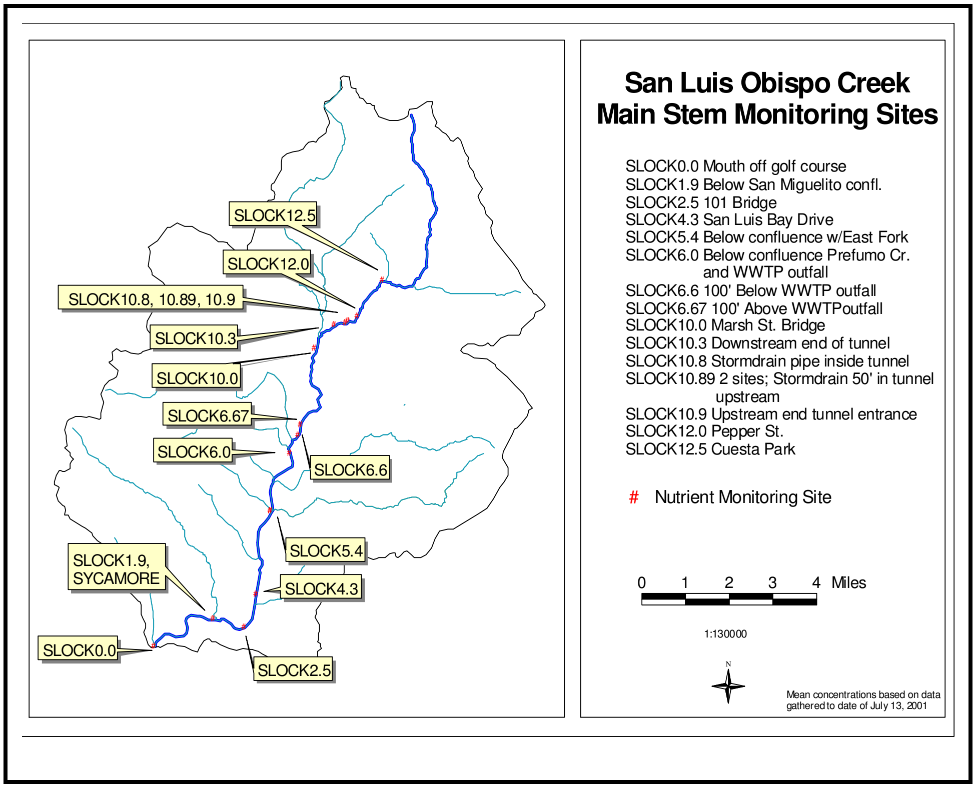

Figure 3.2 Regional Board Monitoring Stations along San Luis Obispo Creek

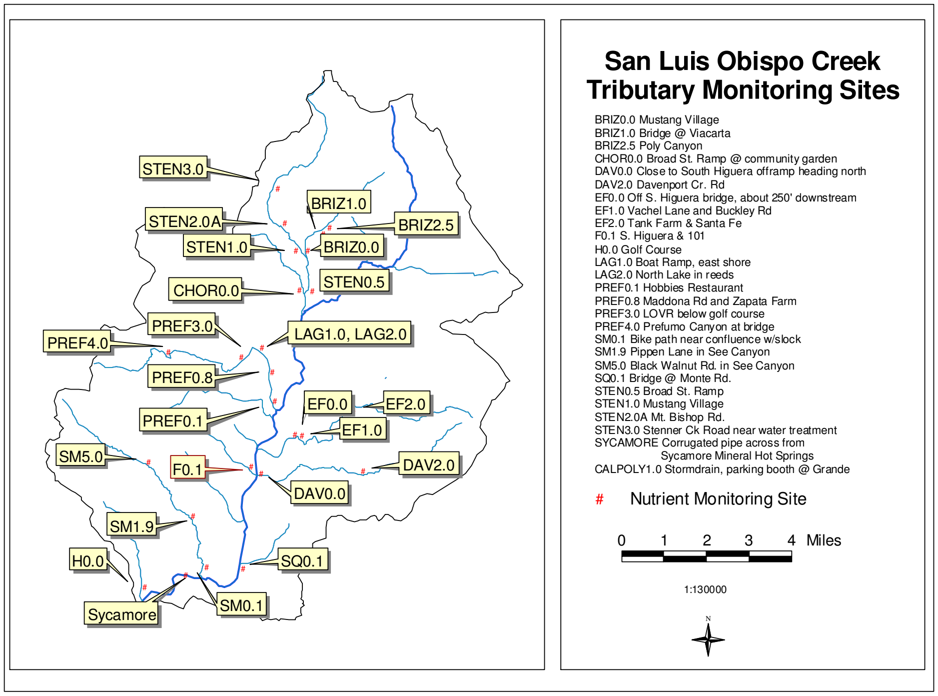

Figure 3.3 Regional Board Monitoring Sites along tributaries to San Luis Obispo Creek

3.2.3 City Monitoring and Reporting

The City is required to monitor and report under their Monitoring and Reporting Program (Program) No. 01-05 for the Water Reclamation Facility (on file at Central Coast Regional Water Quality Control Board). Methods of collection, frequency, reportable limits, and analytical methods, are documented in the Program and meet Regional Board standards.

The City monitors effluent from the plant for various constituents, including NO_2 and NO_3, dissolved phosphorus, total phosphorus, and flow. The City also monitors 7 sites along the main stem of the Creek, as well as one of its tributaries, and is referred to as the Creek Monitoring Program. The Creek Monitoring Program monitors temperature, dissolved oxygen, NO_2 and NO_3, algae cover, and flow from April through November.

Monitoring data from Staff monitoring efforts were compiled in an MS Excel spreadsheet. The laboratory electronically reports sample analysis in MS Excel format, which are subsequently incorporated into the larger spreadsheet by staff. The laboratory follows electronic copies with hard copies of sample analysis, which are used by staff to check the electronic file data for consistency. Data collected from the YSI and Hydrolab units is saved electronically in the field, and then downloaded in spreadsheet format. Data collected with the densiometer is recorded in the field on field sheets, which is recorded by hand into the data spreadsheet.

Monitoring reports from the City are delivered by hand in hard copy. Data from these reports are entered by hand into the larger spreadsheet.

3.2.4 Data Management

Elements of the flowchart of Figure 3.1 were completed by querying data from the spreadsheet using MS Access. Key data points were queried, resulting in tables that were exported to MS Excel spreadsheet files for further analysis, e.g. graphing.

3.2.5 Geographic Data

Watershed and subwatershed areas were determined using GIS software. Watershed boundary polygons were manually delineated using 30-meter digital elevation model data. Watershed and subwatershed boundary polygons were overlayed with land use data to obtain land use polygons within subwatershed boundaries. The land use data was obtained from digital land use data compiled by the United States Geological Society (USGS); the EPA modeling Software Basins, Version 3.0 (USEPA[1], 2001), includes this land use data set. Staff obtained the land use data through this software package. Land use polygons requiring ground-truthing were done so by field reconnaissance and digital orthophotos.

Fourteen separate land use categories resulted from the overlay of land use data and subwatershed data. Staff in turn aggregated the fourteen land use categories into 6 categories based on observed similar water-quality data. The 6 land use categories are:

1. Natural (includes forests, range, shrub-land, and transitional areas)
2. Reservoir
3. Commercial/Urban (includes commercial, industrial, and roadways)
4. Residential
5. Confined animal operations
6. Cropland.

3.3 Land use

Land uses were delineated on a watershed and subwatershed basis. Ten subwatersheds have been delineated for the purpose of this TMDL. However, in some cases, further refinement was needed in subwatersheds delivering significant nutrient loads. A more detailed discussion is provided in sections to follow. Figure 3.4 below illustrates the subwatersheds in the system.

The watershed supports 6 land uses in an area of 84.6 mi^2, or 54,142 acres. Table 3.2 below identifies the total area of each land use category as well as the relative area it occupies. Figure 3.5 below illustrates the land use distribution in the Watershed.

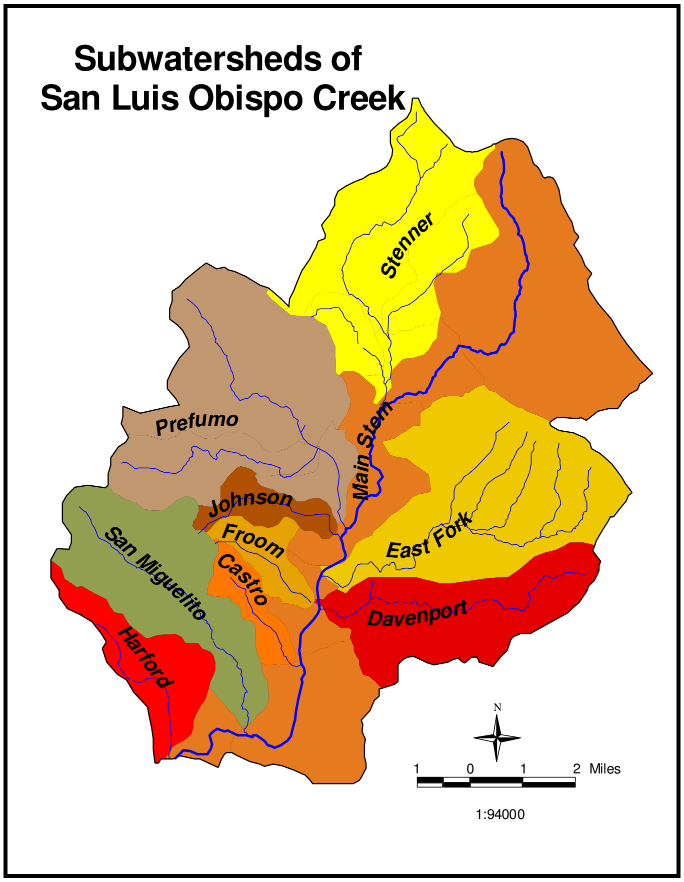

Figure 3.4 Subwatersheds of San Luis Obispo Creek

Table 3.2 Land uses in San Luis Obispo Creek Watershed

Land use	Area (acres)	Relative Area (%)
Natural	40618	75.02
Commercial/Urban	2782	5.14
Confined animal operations	39	0.07
Cropland	7651	14.13
Reservoirs	106	0.20
Residential	2947	5.44
TOTAL	54142	100.00

Note from Table 3.2 that natural and croplands are the dominant and subdominant land use types in the Watershed, respectively. Figure 3.4 illustrates the Watershed and its delineated subwatersheds. Figure 3.5 illustrates the land uses within each subwatershed.

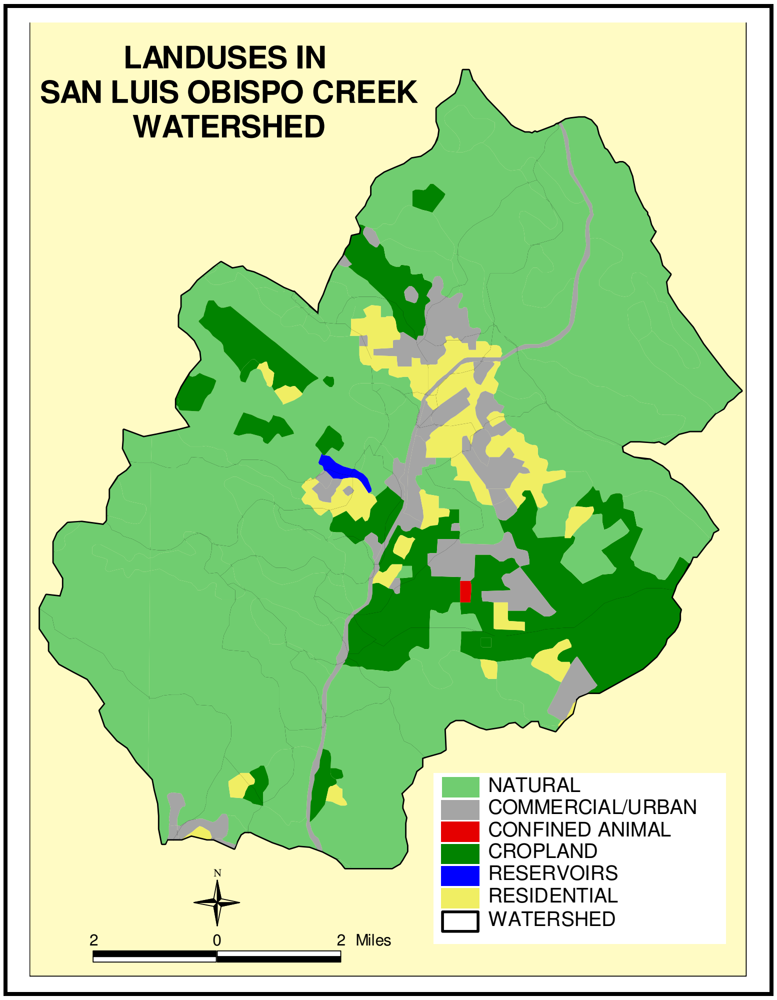

Figure 3.5 San Luis Obispo Creek Watershed Land uses

It is clear from Figure 3.5 that the dominant land use in the watershed is natural.

Table 3.3 below identifies land uses and their respective areas within each subwatershed.

Table 3.3 Land use and relative area by Subwatershed

Subwatershed:	Castro Canyon	
Land uses	Area (acres)	Relative area (%)
Natural	992.8	100

Subwatershed:	Davenport	
Land uses	Area (acres)	Relative area (%)
Natural	2135.3	47.2
Commercial/Urban	231.7	5.1
Cropland	1950.8	43.1
Residential	204.8	4.5
Total	4522.6	100.0

Table 3.3 Continued

Subwatershed:	East Fork	
Land uses	Area (acres)	Relative area (%)
Natural	3575.9	45.5
Commercial/Urban	836.3	10.6
Confined Animal OPS	38.6	0.5
Cropland	2663.2	33.9
Residential	739.9	9.4
Total	7853.8	100.0

Subwatershed:	Froom	
Land uses	Area (acres)	Relative area (%)
Natural	1059.4	99.1
Cropland	10.0	0.9
Total	1069.4	100.0

Subwatershed:	Harford	
Land uses	Area (acres)	Relative area (%)
Natural	2218.7	96.2
Commercial/Urban	86.6	3.8
Total	2305.3	100.0

Subwatershed:	Johnson	
Land uses	Area (acres)	Relative area (%)
Natural	1054.7	100.0
Cropland	0.3	0.03
Total	1055.0	100.0

Subwatershed:	Main stem	
Land uses	Area (acres)	Relative area (%)
Natural	12607.9	83.7
Commercial/Urban	757.7	5.0
Cropland	807.9	5.4
Residential	886.1	5.9
Total	15059.5	100.0

Subwatershed:	Prefumo	
Land uses	Area (acres)	Relative area (%)
Natural	6831.4	76.3
Commercial/Urban	180.9	2.0
Cropland	1408.4	15.7
Reservoirs	106.1	1.2
Residential	429.1	4.8
Total	8955.9	100.0

Table 3.3 Continued

Subwatershed:	San Miguelito	
Land uses	Area (acres)	Relative area (%)
Natural	5105.1	98.4
Cropland	65.9	1.3
Residential	17.7	0.3
Total	5188.8	100.0

Subwatershed:	STENNER	
Land uses	Area (acres)	Relative area (%)
Natural	5036.9	70.6
Commercial/Urban	689.0	9.7
Cropland	744.1	10.4
Residential	669.0	9.4
Total	7138.9	100.0

See accompanying spreadsheet: SLOnutTMDL, "LANDUSES" worksheet.

3.4 Data Analysis

The following discussions will refer to monitoring sites illustrated in Figures 3.2 and 3.3 presented above.

3.4.1 Land use/Source Nomenclature

Six land use categories have been identified in the Watershed, including:

- natural,
- commercial/urban,
- confined animal operations,
- cropland,
- reservoirs,
- residential.

The land use designations will be used in this document as the name of the nutrient source associated with that land use. The only exception will be the land use category of natural; which will be associated with *background* sources.

3.4.2 Significant Nitrate Sources

Staff used main stem water quality data to determine where along the channel significant increases in nitrate levels occur. Data points were tabulated and graphed as a function of distance upstream from the mouth. Notable increases in nitrate concentration were then tested for significance using statistical software. Statistical tests compared nitrate concentrations of sites where an increase was evident to the site immediately upstream. The analysis aided staff in determining where significant nitrate sources are located. Figure 3.6 below illustrates nitrate values along the main stem of the channel. The x-axis refers to locations along the main stem of the Creek. Monitoring stations are geographically illustrated in Figures 3.2 and 3.3 in the preceding section.

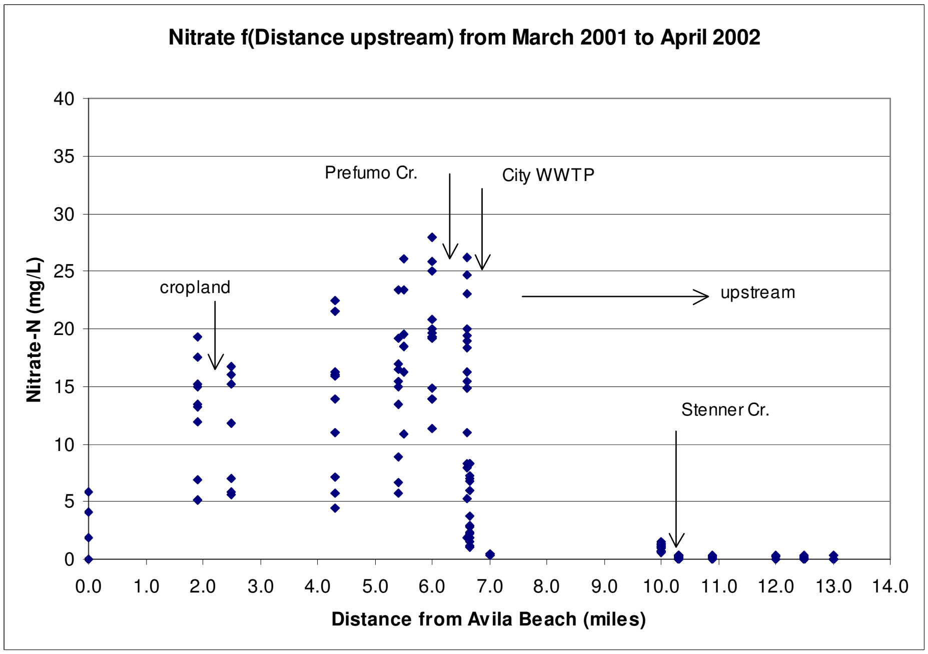

Figure 3.6 Nitrate levels along main stem

See accompanying spreadsheet: SLOnutTMDL, "NITRATE" worksheet, cell BP2.

Note in Figure 3.6 that nitrate levels slightly increase immediately downstream of:

1. The confluence with Stenner Creek.
2. The confluence with Prefumo Creek.
3. The discharge of the city waste water treatment plant (WWTP).
4. Downstream of a cropland area.

The sites described in bullets 1-4 above correspond to monitoring sites 10.0, 6.6, 6.0, and 1.9, respectively, and are illustrated in Figure 3.2. Staff used the Mann-Whitney non-parametric analysis to test if median nitrate concentration significantly increases at these sites, relative to the adjacent upstream sites. An alpha level of 0.05 is used to test significance. The results of the analysis are summarized in Table 3.4 below.

Table 3.4 Test for significant increases in median nitrate concentration using Mann-Whitney Test

Site	Is median NO_3 concentration statistically > than upstream?	P-Value
10.0	Yes	0.0000
6.6	Yes	0.0000
6.0	Yes	0.0328
1.9	No	0.4611

See full analysis in Appendix.

The analysis indicates that the median nitrate concentration at sites 10.0, 6.6, and 6.0 is statistically greater than the sites immediately upstream from each of the sites. The results of the analysis are reasonable as each of these sites is immediately downstream of either a tributary or point source. Tributary and point source data further corroborate results of the statistical analysis, as discussed below.

3.4.2.1 Stenner Creek

Site 10.0 is a main stem site immediately downstream from the confluence with the tributary Stenner Creek. The median nitrate concentration in Stenner Creek for the year of record is 1.80 mg/L-N, flowing at an average rate of 5.6 ft^3/sec. The median nitrate concentration at site 10.3 (site above site 10.0 and confluence with Stenner Cr.) is 0.075 mg/L-N. The resulting median nitrate concentration downstream of the confluence is 0.95 mg/L-N. It is apparent that the higher concentration of nitrate flowing from Stenner Creek into the main stem of San Luis Obispo Creek is causing an increase in nitrate concentration in the main stem. Figure 3.7 below illustrates how the confluence affects nitrate concentrations in the main stem.

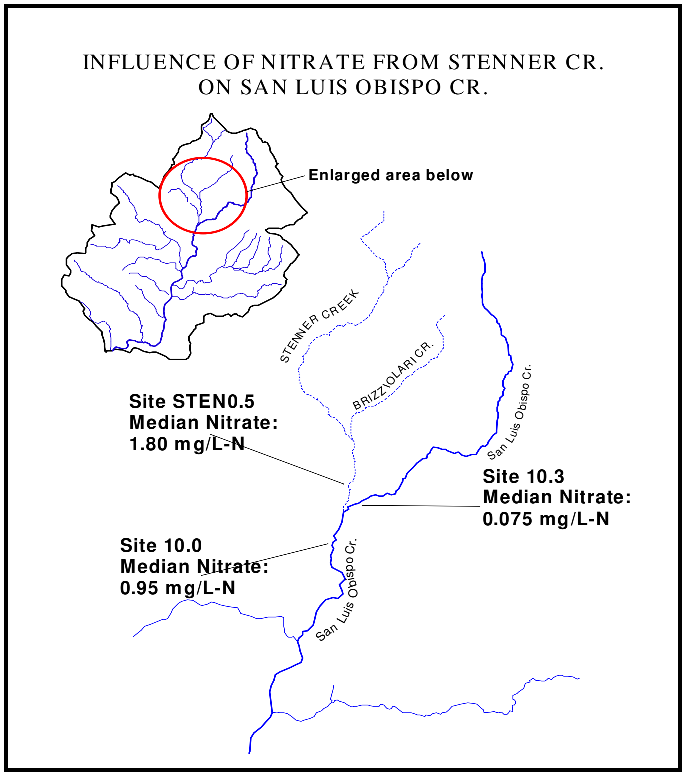

Figure 3.7 Confluence of Stenner Creek and San Luis Obispo Cr.

See accompanying spreadsheet: SLOnutTMDL, "NITRATE" worksheet, cell BW33.

Land use activities in Stenner Creek subwatershed are illustrated in Table 3.3 above. Note that the dominant land use in Stenner Creek subwatershed is natural. Staff have reviewed data and have determined that background nitrate concentrations average 0.09 mg/L-N. The subdominant land use activity is cropland. Staff have determined that the average nitrate concentration adjacent to other croplands in the Watershed is 26 mg/L-N. In addition, water quality sampling along the tributary Brizziolari Creek indicate an increase in nitrate concentration downstream of a small bull-pen, where animals are confined near the waters edge (see data at monitoring sites BRIZ1.0 and BRIZ2.5); average concentrations upstream of the pen are 0.24 mg/L-N, and 0.98 mg/l-N downstream of the pen.

Staff, therefore, conclude that:

- The elevation in nitrate at site 10.0 along the main stem of the Creek is due to primarily to cropland activities in Stenner Creek subwatershed and confined animal operations along Brizziolari Creek.
- The nitrate concentration in Stenner Creek is well below the TMDL numeric target.
- Elevated nitrate concentration from Stenner Creek does not cause nitrate levels downstream of the confluence with San Luis Obispo Creek to rise above the numeric target.

3.4.2.2 City of San Luis Obispo Water Reclamation Facility

Site 6.6 is a main stem site immediately downstream of the point-source discharge from the City of San Luis Obispo's Water Reclamation Facility. The median concentration of nitrate from the discharge for the year of record is 23.6 mg/L-N, flowing at an average rate of 4.3 million gallons/day. The median nitrate concentration at the site upstream of the discharge is 0.95 mg/L-N. The median nitrate concentration immediately downstream of the WRF discharge is 15.15 mg/L-N for the year of record. The volume of flow from the discharge represents a significant proportion of the total stream volume at site 6.6. Figure 3.8 below illustrates the influence of the WRF on nitrate levels in the Creek

The information presented lead staff to conclude that:

- The elevation in nitrate concentration at site 6.6 along the main stem of the Creek is due to nitrate loading from the WRF, located immediately upstream of site 6.6, and is a significant source of nitrate to downstream waters.
- Discharge from the WRF causes nitrate concentration in the Creek to rise above the numeric target for nitrate of 10.0 mg/L-N.

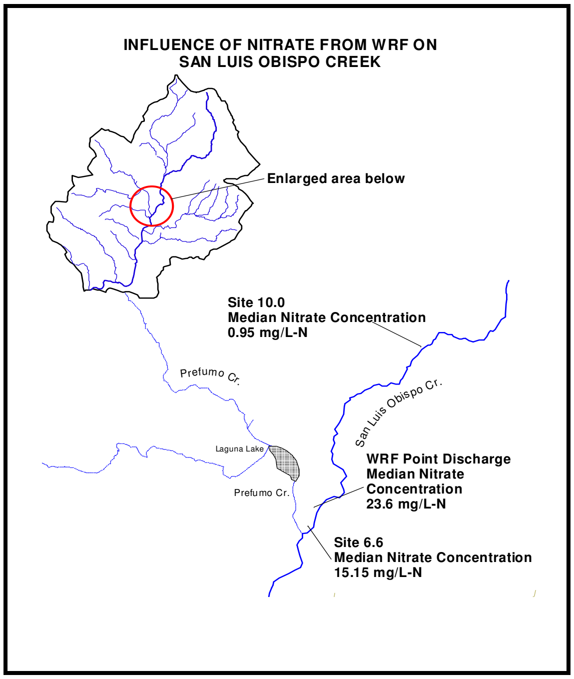

Figure 3.8 Nitrate Concentration Downstream of WRF

See accompanying spreadsheet: SLOnutTMDL, "NITRATE" worksheet, cells BY53 and DY22.

3.4.2.3 Prefumo Creek Subwatershed

Site 6.0 is a main stem site immediately downstream from the confluence with the tributary Prefumo Creek. The median nitrate concentration flowing from Prefumo Creek at the confluence with San Luis Obispo Creek is 31.0 mg/L-N, flowing at an average rate of 1.7 ft^3/sec. The median nitrate concentration at the site above the confluence, i.e., site 6.6 is 15.15 mg/L-N, resulting in a median nitrate concentration below the confluence of 19.3 mg/L-N at site 6.0. Figure 3.8 below illustrates how the confluence affects nitrate concentrations in the main stem.

Notice from Table 3.3 above that the dominant land use in Prefumo Creek watershed is natural, with the subdominant land use being cropland. The cropland area occurs near the confluence of Prefumo Creek with the San Luis Obispo Creek, whereas the natural areas occur in the north and west portions of the watershed.

Data analysis of monitoring points located in the watershed (see Figure 3.3, PREF sites) clearly indicate that nitrate loading into San Luis Obispo Creek from Prefumo Creek is largely due to croplands. The following considerations support this determination:

- The average nitrate concentration in Prefumo Creek below cropland activities is 26.3 mg/L-N, whereas the average nitrate concentration immediately upstream of the cropland activity (which is discharge water from Laguna Lake) is 0.09 mg/L-N.
- The average nitrate concentration in Laguna Lake, as well as below residential and natural areas which provide flow to the downstream cropland area, is 0.06 mg/L-N (see land use maps above, Figure 3.5).

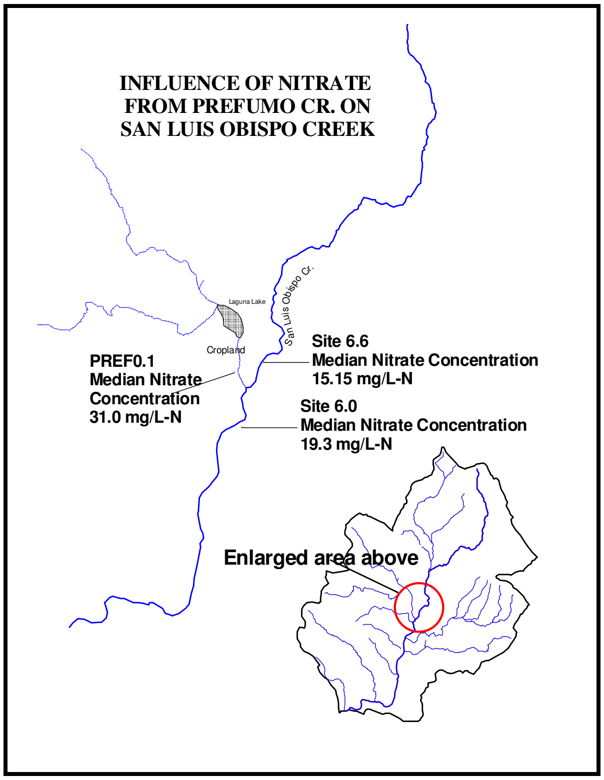

Figure 3.9 Confluence of Prefumo Creek and San Luis Obispo Creek

See accompanying spreadsheet: SLOnutTMDL, "NITRATE" worksheet, cells BW33 and CN53

3.4.2.3.1 Nitrate Regime and Land Use Change in Lower Prefumo

It is important to note that although there is a statistically higher median nitrate concentration downstream of the confluence with Prefumo Creek, relative to upstream of the confluence, the nitrate loading from Prefumo Creek into San Luis Obispo Creek is not large enough to cause exceedence of the numeric target in San Luis Obispo Creek. Staff have determined that whether the WRF discharge is present and discharging at the numeric target or whether it is not discharging at all, the nitrate mass from Prefumo Creek into San Luis Obispo Creek does not cause an exceedence of the numeric target in San Luis Obispo Creek. This will be an important distinction when considering options for implementing the TMDL with the objective of achieving the numeric target.

There are approximately 300 acres in cropland production in the lower Prefumo Creek Watershed, i.e., downstream of Laguna Lake. It is this cropland area that is largely responsible for the nitrate loading from Prefumo Creek. However, approximately 25% of this area will be developed beginning in 2005 and is being converted to retail land use. Another 25% of this area is being deeded and annexed to the City of San Luis Obispo. The land use after the annexation is not yet determined, but it is probable that this area will not be in crop production.

Finally, it is anticipated that growers remaining (after the land use conversion) in the Prefumo Creek watershed will take management measures aimed at meeting the numeric target. This is anticipated because the impending Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Agricultural Waiver) will require growers to take such action.

Therefore, it is expected that the Prefumo Creek source of nitrate to San Luis Obispo Creek will be significantly reduced during, and perhaps before, the implementation phase of this TMDL.

3.4.2.4 Main stem site 1.9

Note from Table 3.4 that the increase in nitrate at site 1.9, relative to the monitoring site upstream of site 1.9, is not statistically significant. Staff, therefore, conclude that land uses immediately upstream of site 1.9 are not increasing nitrate concentrations in the Creek. In addition, subsequent to the data collection period, a land use change has occurred at this site. This site was adjacent to an irrigated agriculture field that has been developed and converted into commercial buildings.

3.4.2.5 Summary of Nitrate Sources

Table 3.5 below identifies the sources of nitrate to the Creek. Sources listed in the table are not the only sources of nitrate, but represent those that have a statistically significant impact on the Creek. Again, although all the sources listed in Table 3.5 result in a measurable increase in nitrate concentration in San Luis Obispo Creek, the point source is the only source that causes exceedence of the numeric target.

Table 3.5 Significant nitrate sources

Source	Location
Cropland	Stenner Creek subwatershed
Cropland	Prefumo Creek subwatershed
Point source	City’s Water Reclamation Facility

3.4.2.6 Other Sources of Nitrate

Other sources of nitrate to the Creek include those that are present, but do not create a measurable (statistically significant) impact to Creek concentration. It is clear that all land use types contribute nitrate to some degree, insofar as all land use types play a role in nitrogen cycling. Although other sources of nitrate may not have a measurable impact to the Creek, it is necessary to list these sources as it will become necessary to quantify their contribution to total loading.

Sources that were *not* accounted for in Section 3.4.1include:

- Background
- Residential
- Commercial/Urban
- Reservoir
- Atmospheric deposition

3.4.2.6.1 Background, Residential, and Commercial/Urban Sources

The headwaters of the Creek begin in areas that are relatively undisturbed, i.e., in areas considered to contribute background levels of nitrate. The Creek then flows in a southwesterly direction through residential then commercial/urban areas of the City of San Luis Obispo. Staff have compiled water quality data from locations along the Creek where land use changes occur. This has enabled staff to make conclusions regarding loading from these land use activities.

The following monitoring sites were chosen to aid staff in determining nutrient loading due to various land uses (refer to Figure 3.2 above):

- Site 12.5; situated upstream of the City limits, draining areas from background sources,
- Site 13.0; situated upstream of site 12.5, is also draining areas from background sources; monitored by the City staff.
- Site 12.0; situated downstream of site 12.5, draining areas flanked by residential land use on both side of the Creek,
- Site 10.9; situated downstream of site 12.0, draining areas flanked by commercial/urban land use on both sides of the Creek,
- Site 10.3, situated downstream of site 10.9, draining areas flanked by commercial/urban land use on both sides of the Creek.

Figure 3.10 below graphically illustrates the minimum, maximum, and average nitrate concentrations for each site referred to above. Because all sites are adjacent to each other, with natural sites being furthest upstream, staff noted whether nitrate levels increased while flowing from background sources through residential and urban/commercial.

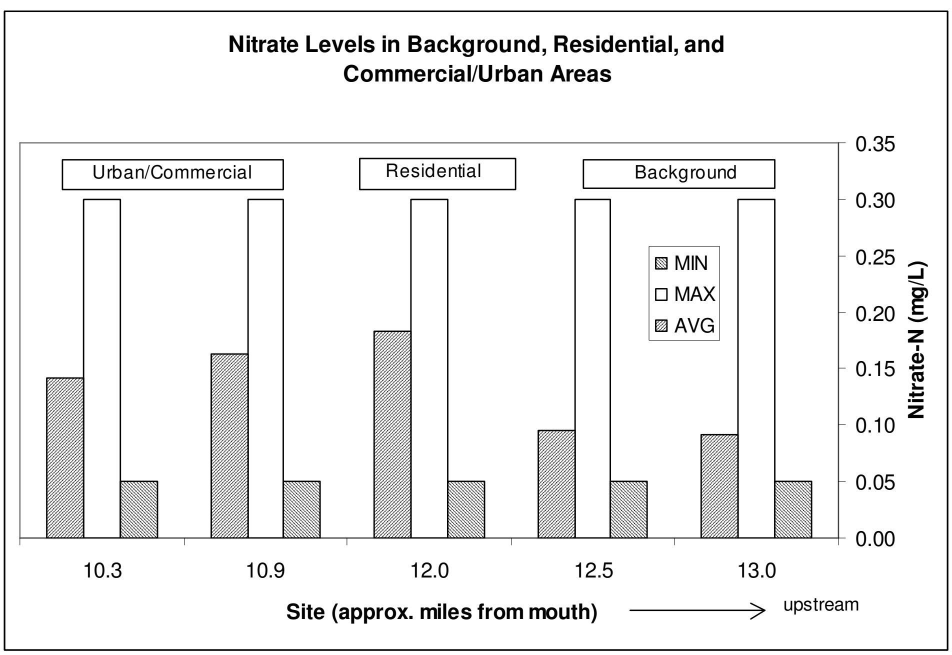

Figure 3.10 Minimum, maximum, and average nitrate levels among land uses.

The following observations can be made of Figure 3.10:

- Maximum nitrate levels do not increase while flowing from natural through residential or urban/commercial areas.
- Minimum nitrate levels do not increase while flowing from natural through residential or urban/commercial areas.
- Average nitrate levels slightly increase (from 0.10 mg/L at 12.5 to 0.18 mg/L at 12.0), over background levels, after flowing through residential areas.
- Average nitrate levels slightly decrease in urban/commercial areas, relative to residential.
- All levels, including maximum nitrate levels, fall well below the proposed numeric target.

Note that because there is not a tributary or point source between sites 12.0 and 12.5, that the volume of water flowing past either site is approximately the same. Also note that site 12.5 carries loading from background sources whereas site 12.0 carries loading from background and residential sources. Therefore, a ratio of residential to background loading can be determined and used in the loading analysis. The ratio of residential to background loading is:

$$\text{Where } L = \text{Loading} = \text{Discharge } (Q) \times \text{Concentration } (C)$$
$$\text{Therefore: } Q_{12.0}C_{12.0} = Q_{Background}C_{Background} + Q_{Residential}C_{Residential}$$
$$\text{Since } Q_{12.0} = Q_{12.5}$$
$$C_{12.0} = C_{Background} + C_{Residential}$$
$$\text{Therefore: } C_{Residential} = C_{12.0} - C_{Background} = 0.18 - 0.10 = 0.08$$

The ratio therefore becomes:

$$\frac{residential...loading}{background...loading} = \frac{0.08}{0.10} = 0.8$$

Staff have made the following conclusions based on the observations above:

1. Residential loading is approximately 0.8 of background.
2. Commercial/urban sources are negligible.

3.4.2.6.2 Reservoirs

Laguna Lake is situated in Prefumo Creek subwatershed. The lake outlet is the continuation of Prefumo Creek (refer to Figure 3.8 above), and flows through cropland. Staff conducted monitoring near the outlet of Laguna Lake, and have quantified the nitrate contribution of the lake to the Creek (refer to section 3.4.2.3 above). The contribution is minimal, relative to the contribution due to cropland. However, the lake does deliver some nitrate, and will be considered in the loading analysis. Furthermore, because the lake captures loading by sources that flow to the lake, e.g. natural and residential areas, these sources will not be considered in the loading analysis as they will already be accounted for as a reservoir source.

Similar to the ratio determination in Section 3.4.2.6.1, the ratio of reservoir sources to cropland sources is determined as follows:

$$\text{Where } L = \text{Loading} = \text{Discharge } (Q) \times \text{Concentration } (C)$$
$$\text{Therefore: } Q_{Pref0.1}C_{Pref0.1} = Q_{Reservoir}C_{Reservoir} + Q_{Crop}C_{Crop}$$

$$\text{Since } Q_{Pref0.1} = Q_{0.7}$$
$$C_{Pref0.1} = C_{Reservoir} + C_{Crop}$$
$$\text{Therefore: } C_{Crop} = C_{Pref0.1} - C_{Reservoir} = 26.30 - 0.09 = 26.21$$

The ratio therefore becomes:

$$\frac{reservoir...loading}{cropland...loading} = \frac{0.09}{26.3} = 3.43 \cdot 10^{-3}$$

Staff have therefore concluded that:

- Sources of nitrate due to reservoirs in the Watershed are a factor 3.43 * E^{-3} that of the cropland area in the Prefumo watershed.

3.4.2.6.3 Atmospheric Deposition

Atmospheric deposition can be a significant source if a lake or reservoir is present, particularly if the area of the lake or reservoir is a significant portion of the entire watershed. This, however, is not the case with Laguna Lake in the Watershed.

Laguna Lake encompasses 106 acres of the 54,142-acre watershed, making the lake 0.19% of the total watershed area. Additionally, any atmospheric deposition occurring will be accounted for in the reservoir source category. Staff have therefore concluded that:

- Atmospheric deposition is not a significant source of nitrate in the Watershed.
- Any atmospheric deposition occurring will be accounted for in the reservoir source category.

3.4.2.6.4 Other Cropland Areas

The *other cropland* source category include those areas not explicitly discussed above. Although other cropland areas are not significantly impacting nitrate concentrations along the main stem, nitrate loading is present.

East Fork and Davenport subwatersheds support 4600 acres of cropland (see land use map). They are located in the lower half of San Luis Obispo Creek Watershed in an area of low gradient, resulting in lower water velocities, which in turn supports infiltration. East Fork and Davenport are ephemeral streams, being two of the first tributaries to stop flowing as summer approaches; they had minimal flows from November 2001 until flow ceased in April 2002. Additionally, much of the cropland is not adjacent to the main stem of San Luis Obispo Creek, and some of the crops are dry-farmed only. Finally, a significant vegetative buffer strip flanks San Luis Obispo Creek in this area. As a result of these features, East Fork and Davenport deliver lower nutrient loads to San Luis Obispo Creek, relative to other cropland areas, and helps explain why a significant increase in median nutrient concentrations is not observed below their confluence with San Luis Obispo Creek.

An analysis of data collected at the mouths of Davenport and East Fork Creek indicate the following:

- Davenport Creek delivers non-detectable levels of nitrate to San Luis Obispo Creek,
  - Although nitrate levels are non-detectable, staff use ½ detection limit for loading calculation, as some minimal amount of loading must occur.
- East Fork delivers an annual average of 2.68 mg/L NO^3-N to San Luis Obispo Creek.

3.4.2.7 Summary of Other Nitrate Sources

Table 3.6 below identifies other sources of nitrate, i.e., those that are present but not significantly impacting nitrate concentrations in the main stem. The list below is based on the findings discussed above.

Table 3.6 Other nitrate sources

Source	Location
Background	Many
Residential	Primarily w/in City of San Luis Obispo
Reservoir	Laguna Lake
Croplands	Davenport and East Fork

3.4.3 Sources from Future Development

The potential exists for development within the watershed that would impact the sources of nutrients to the Creek. However, staff believe that development within the watershed will not add significant nitrate loading. This determination is made for the following reasons:

- Future development will increase residential and commercial/urban land uses, and
  - it was demonstrated above that residential commercial/urban nutrient sources are negligible.
- Development will primarily occur in existing cropland areas:
  - Conversion of cropland land use to residential or commericial/urban will have a net decrease in nutrient loading (supported in loading analysis section).
  - Current development proposals include a large land use conversion from cropland to commercial in the Prefumo Creek subwatershed. The development is expected to commence in 2005, and is likely to significantly reduce nitrate loading from this cropland source (refer to Section 3.4.2.3.1).

4 Load Analysis

4.1 Introduction

The load analysis section identifies the total and relative mass loading of nitrate for each of the sources identified in the previous section. The loading analysis sets the stage for the next section, the linkage analysis, which in turn will be used to develop the TMDL.

4.2 Methods Used to Determine Nitrate Mass Loading

4.2.1 Nitrate Non-point Source Loading

Both in-stream nitrate concentration and flow data are needed at each point where mass loading is to be determined. Staff utilized concentration data obtained from March 2001 to April 2002 for loading calculations. Data prior to March 2001 were obtained from various sources, including results of the City's monitoring efforts for their NPDES permit of the WRF. The City's data strongly corroborates the findings of staff insofar as:

1. Peak main stem nitrate concentrations occur downstream of the WRF discharge.
2. The highest main stem nutrient concentrations occur during late summer.
3. Background nitrate levels are less than 0.5 mg/L-N.

Staff utilized flow and nutrient data collected by City staff as well as that collected by Regional Board staff. Unfortunately, the dates of nutrient and flow data are not always the same; if they were, staff could calculate the loading for that day. Therefore, staff *calculated* the flow present at the time and place a nutrient concentration sample was taken by interpolating between measured flow data points. Staff utilized linear algebra to estimate what the true flow was during the day a water quality sample was collected. Staff is confident this method will accurately reflect the true flow to a level of precision needed to make management decisions, i.e., relative loading and loading allocations. Staff is confident of this method for the following reasons:

- Flow measurements were not taken during a rising or falling limb of the hydrograph, therefore instantaneous measured flow volume closely reflects the true mean value for a day of flow.
- Error will not be significant because there were not large disparities in flow volume from one sampling event to the next; the latter is so because event monitoring was not used to develop loading calculations.

Figure 4.1 below illustrates the method for calculating flow between two measured data points.

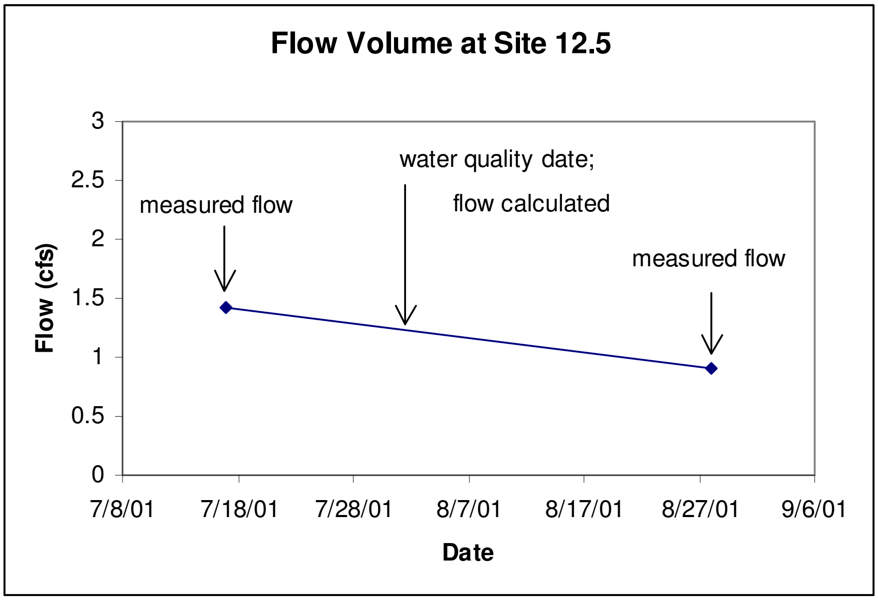

Figure 4.1 Example of method for calculating flow between two measured points.

The calculated flow and measured concentration was then used to determine nitrate loading at the monitoring point where the water quality data point was taken. The daily loading was established at the monitoring point, based on the assumption that the nitrate concentration from a sampling point reflected levels throughout that day. Daily loadings were calculated at monitoring sites located at the mouth of tributaries draining subwatersheds. With this approach, the total loading from subwatersheds could be summed to determine the total loading in the watershed. This approach also lends itself to identification of key areas where loading is the greatest.

Daily loads were then plotted as a function of time from March 21, 2001 to March 21, 2002. These are the dates staff conducted water quality monitoring. The daily loads act as known measured loading points between which calculated loading could be determined; known daily loading points were used as two points of a line, under which is the sum of nitrate loading for the period between the two points. The area under the line (total loading for the period) was determined by:

1. Determining the equation of the line between the two known points.
2. Finding the area under the line between the two known points using integration.

Figure 4.2 illustrates how nitrate loading between two known loading points was determined.

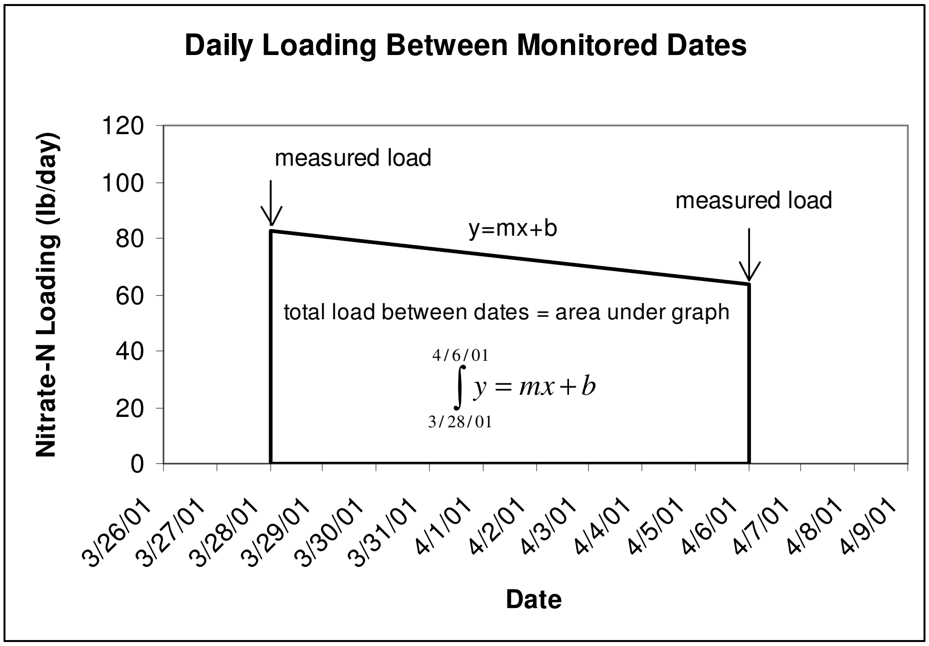

Figure 4.2 Determining nitrate loading between two monitoring dates

Where: y is load in lb/day, m is the slope of the line, x is number of days past 3/21/01, and b is the y-intercept. See accompanying spreadsheet: SLOnutTMDL, "MeasuredLoad and MeasuredWLoad" worksheets for integration calculations.

Note from Figure 4.2 that the integral was performed on the function derived between loading analysis points. Consequently, several integrations were preformed for each source, e.g. from 03/21/01 to 03/28/01, then again from 03/28/01 to 04/06/01, and so on through 03/21/2002, for each monitoring point where data was available. As a result, the total loading for the year of record for each monitoring site is:

$$\text{Total annual loading at a site} = \sum \int_{date-a}^{date-b} y = mx + b \ldots \int_{date-b}^{date-c} y = mx + b \ldots$$

Once the total annual load was determined by subwatershed, the total load was distributed among various sources present in that watershed. The distribution of the total load was accomplished by first determining a loading flux rate for the background source.
A flux rate is the loading mass per acre of land use over a period of time, for example pounds per acre per year (lb/ac/yr) from natural areas in a subwatershed.

The flux rate was determined for background sources using the monitoring site SLOCK12.5, above which is a natural (background) source. The area of land used was all area within 50-meters of a tributary of the main stem occurring in the watershed above the monitoring site

SLOCK12.5. The 50-meter buffer was used because it is this land-area contributing the greatest proportion of nutrients to the Creek (Hallock *et al*, 1994); using the entire land area of background sources (even those far away from a stream) in a subwatershed could overestimate loading. The 50-meter buffer around the streams was accomplished using a GIS. The buffered area was then intersected with the land use data to obtain land use areas occurring within 50-meter of the stream.

The following components were used to determine the flux rate for the background source:

1466 acres = Natural area within 50-meter of stream above site 12.5

579 lb-NO_3-N/year = loading at site 12.5 for the year of record

0.395 lb/ac/yr = flux rate for background source

Once the background flux rate was determined, loading due to background sources in a subwatershed could be calculated. The loading due to background sources was then subtracted from the total load. The remaining load to be distributed would depend on the sources remaining in the subwatershed:

- For residential, loading is 0.08 that of background (see section 3.4.2.6.1 above).
- For reservoir, only one source is present occurring in the Prefumo Creek Watershed. Loading is calculated as 3.43×10^{-3} of croplands in this watershed. The total loading in Prefumo Creek watershed is calculated with concentration and flow data.
- Urban/commercial is a negligible source (see section 3.4.3.1 above).
- For confined animal operations, the load is that remaining after all other sources have been accounted for.

The largest cropland areas occur in Prefumo, East Fork, and Davenport subwatershed areas. Monitoring data along the tributaries for these subwatersheds was used to determine total loading, which was then used to back-calculate for the sources discussed above. However, relatively small subwatersheds along the main stem have some cropland areas for which loading needed to be determined. A flux rate was calculated for these areas along the main stem using the calculated total loading (from monitoring) and cropland areas in Prefumo Creek subwatershed. The total cropland area was used to develop the rate, rather than the area falling within 50-meter of the Creek because the cropland areas lack riparian vegetation, and often have drains returning field water to the Creek. As a result, it is more likely that nutrients applied to a cropland area a distance away from the Creek will be transported to the Creek, relative to natural areas with dense vegetative cover.

Recall that a relatively small portion of the loading from Prefumo Creek is from sources other than cropland, i.e. Laguna Lake (See Section 3.4.2.6.2). This proportion was quantified above as 3.43×10^{-3} of the cropland area in Prefumo. Since the total loading in Prefumo was determined using the monitoring data, the approximate cropland source can be calculated using:

$$\text{Cropland(C)} + \text{Reservoir(R)} = \text{Total Load(T)}$$
$$C + R = T$$
$$R = 3.43 \times 10^{-3}\ C;\ R = .00343C$$
$$\text{Therefore: } C + .00343C = T$$
$$1.00343C = T$$

$$C = \frac{T}{1.00343}$$

and T = 67,787 lb NO_3-N/year, so

$$C = \frac{67{,}787}{1.00343} = 67{,}555 lb$$

Total Cropland area in Prefumo is 1408 acres, therefore
48.0 lb/ac/yr = flux rate for cropland sources

This flux rate is quite similar (48.0 lb/ac/yr) to the flux rate determined for cropland sources in a 1994 nutrient study of San Luis Obispo Creek Watershed (Hallock *et al*, 1994). Note that the flux rate for cropland areas is only used in the absence of monitoring data.

A confined animal flux rate was needed to determine nitrate loading due to this source. Staff obtained upstream/downstream monitoring data from a background and confined animal area to determine a ratio of loading between the two. A flux rate for confined animal operations was then calculated using the developed flux rate for background sources. This method of determining the flux rate is appropriate under the following assumption:

- That loading from the natural source (background levels) upstream of the confined animal operation results from load/uptake rates that are similar per unit of background area.

This assumption is necessary because the background and confined animal land areas are not equal. The method and assumption is reasonable because:

1. The background area above the confined animal area is uniform.
2. The area of land used for confined animal operations in the watershed is almost negligible.

The flux rate was determined as follows:

Where L = Loading = Discharge (Q) x Concentration (C)

Therefore: $Q_{BRIZ1.0}C_{1.0} = Q_{Background}C_{Background} + Q_{Confined\ animal}C_{Confined\ animal}$

Since $Q_{Briz1.0} = Q_{Briz2.5}$ (BRIZ2.5 draining background area)

$C_{Briz1.0} = C_{Background} + C_{Confined\ animal}$

Therefore: $C_{Confined\ animal} = C_{Briz1.0} - C_{Background} = 0.98 - 0.24 = 0.74$

The ratio of confined animal to background then becomes:

$$\frac{confined...animal...loading}{background...loading} = \frac{0.74}{0.24} = 3.08$$

and

background flux rate = 0.395 lb/ac/yr, therefore
1.22 lb/ac/yr = confined animal operation flux rate for nitrate

Once the total amount of load was distributed for each subwatershed, the loadings from all sources were summed, and relative contributions by sources were then calculated. The result of this calculation are expressed in Table 4.2 below.

4.2.1.1 Negligible Source Areas of Nitrate

Staff have concluded that some watershed areas are contributing negligible masses of nitrate. The following list identifies those areas, and the reasons behind staff's decision:

- Castro Canyon: no observable flow for the year (small watershed area).
- Froom Creek: no observable flow, in addition, flow is discharged to land, not the main stem of the Creek; there is no confluence of Froom and San Luis Obispo Creeks.
- Johnson Creek: flow observed for one month only, relatively little flow with average nutrient concentrations at background levels.
- Harford Canyon: discharges almost directly to the ocean, only impact to San Luis Obispo Creek would be with incoming tide, in addition, nutrient levels are non-detectable.

4.2.2 Point-source Loading of Nitrate

The one point-source contributing nitrate to the Creek is the City's Water Reclamation Facility. Both discharge and receiving water monitoring data are collected by the City.

The discharge data was used to determine the total load from the Facility using two approaches:

1. Total annual load from 03/21/2001 to 03/21/2002 using the same method described above, i.e., utilizing concentration and flow data to determine daily loading, then using the integration function to determine total annual loading, and
2. Using the average nutrient and flow concentration for a month to determine loading for each month between 03/21/2001 and 03/21/2002.

The two approaches yielded slightly different values, with the first approach estimating a higher load. Therefore, the results were averaged to determine the total annual load from the point source. See the accompanying spreadsheet: SLOnutTMDL, "MeasuredWLoad" worksheet, cell B27 for calculations.

4.3 Nitrate Loading by Subwatershed and Watershed

Tables 4.1 and 4.2 below identify the results of the calculations described above. Table 4.1 tabulates loading by source for each subwatershed, as well as the relative contribution of each source by subwatershed. Table 4.2 summarizes Table 4.1 by aggregating the sources for all subwatersheds in order to show loading by source, as well as its relative contribution, for the entire watershed. The accompanying spreadsheet "SLOnutTMDL" contains the individual calculations, please see the worksheet titled "MeasuredLoad."

Table 4.1 Nitrate loading by subwatershed and land use.

Subwatershed name	(lb/yr)	Relative Contribution (%)
Mainstem		
Background	798	2.0
Commercial/Urban	neg.	0.0
Cropland	38,779	97.9
Residential	33	0.1
Sub-total	39,610	100.0
Stenner		
Background	348	2.46
Commercial/Urban	neg.	0.0
Cropland	13,767	97.25
Residential	42	0.29
Sub-total	14,157	100.0
Prefumo		
Background	to lake	0.0
Commercial/Urban	to lake	0.0
Cropland	59,102	99.7
Reservoirs (lake)	203	0.3
Residential		0.0
Sub-total	59,305	100.0
East Fork		
Background	259	4.1
Commercial/Urban	neg.	0.0
Confined animal	14	0.2
Cropland	5,950	95.2
Residential	30	0.5
Sub-total	6,253	100.0
Davenport		
Background	45	78.2
Commercial/Urban	neg.	0.0
Cropland	12	21.8
Residential	neg.	0.0
Sub-total	57	100.0
San Miguelito		
Background	335	9.6
Cropland	3,163	90.4
Residential	2	0.0
Sub-total	3,500	100.0
Castro Canyon	0	
Froom Creek	0	
Harford Creek	0	
Johnson Creek	0	
Total Non-Point Source	122,882	28.8
Total Point Source	304,496	71.2
Total Load	427,378	100.0

Table 4.2 Summary of nitrate contributions by land use throughout the watershed.

Source	NO_3 load (lb/yr)	Relative NO_3 Contribution (%)
Background	1,785	0.42
Confined Animal	14	0.00
Croplands	120,773	28.26
Reservoir	203	0.05
Residential	107	0.02
Point-Source Load	304,496	71.25
Total	427,378	100.0

See worksheet titled “TotLoad” in accompanying spreadsheet file (SLOnutTMDL) for calculations.

It is apparent from the tables above that the point source is the leading source of nitrate in the system.

5 Linkage Analysis

The objective of the linkage analysis is to demonstrate a cause and effect relationship between mass loading and the water quality indicators, i.e., resulting nitrate concentration.

The TMDL assumes a linkage between the source loads and the resulting nitrate loads and subsequent nitrate concentrations. As such, the TMDL calculates the allowable load during the critical flow period using the numeric target. The allowable load is then distributed among the identified sources in proportions calculated from the monitoring data.

6 Assimilative Capacity and Load Allocations

The assimilative capacity, or capacity, of the Stream is the mass of constituent that can be discharged to the stream while still protecting beneficial uses (USEPA, 1999). The Total Maximum Daily Load, or TMDL, is the mass of constituent representing the assimilative capacity. The TMDL is the result of a series of calculations aimed at determining the true capacity. In the case of San Luis Obispo Creek, this report will address the capacity of the Creek to assimilate nitrate without exceeding the numeric target developed in numeric targets section.

The following observations play a role in determining the capacity of the stream:

- Concentration is a function of source loading and stream flow volume (see Linkage Analysis above).
- Loading and flow volume are dependent on time and space, i.e., loading and flow are different at different locations along the Creek.
- Therefore, concentration is time and space dependent.

As capacity is dependent on concentration, and concentration is time and space dependent, capacity is time and space dependent. For example, the assimilative capacity of the Creek at the mouth would be a function of flow volume at the mouth, which in turn is a function of season. Similarly, the capacity at the mouth of the Creek on a particular day of the year is not necessarily equal to the capacity of upstream locations on that day. Therefore, as the allocations set forth in this document must be protective throughout the year at all locations along the stream, a time and space (location) must be chosen for each calculation of capacity.

This conclusion implies that an infinite number of calculations are necessary to determine the TMDL. However, the locations and nature of the significant nitrate sources simplify the process. The following discussion clarifies this point.

6.1 Time and Space Nitrate Levels

Figure 6.1 below illustrates nitrate concentrations from all monitoring sites along the main stem. Staff used monitoring data collected from March 2001 to April 2002 as well as historic data provided by the City collected in accordance with their NPDES permit. The figures below illustrate the time dependence of the capacity calculation.

The horizontal lines on the bars of the graphs in Figure 6.1 denote concentration values observed for all sites monitored along the main stem that month and year. Therefore, the horizontal line at the top of each bar represents the highest concentration observed during a month for all sites monitored.

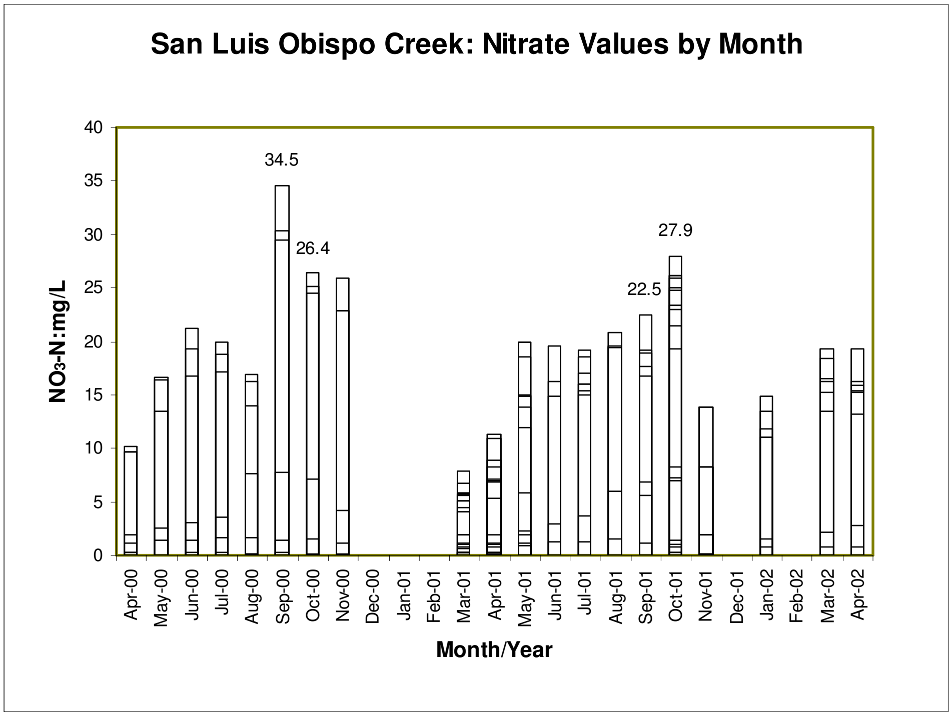

Figure 6.1 Nitrate levels as function of month and year.

*Absence of columns indicate no data available for those months.

Note from the figure above that peak concentrations occur during the late summer months of September and October. It is clear that during this period of time, stream flow volume is at a minimum, and dilution of nitrate is at a minimum.

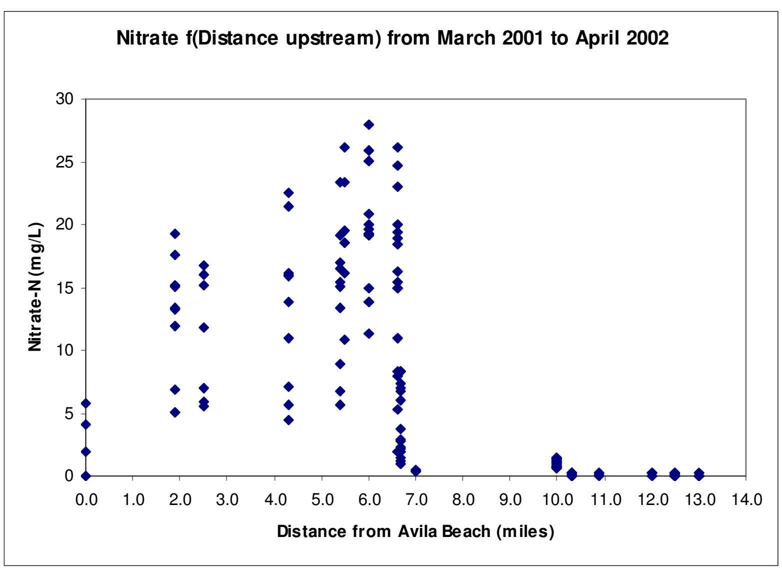

Figure 6.2 Nitrate concentrations along main stem

Figure 6.2 illustrates where (the space component of the capacity calculation) the highest levels occur. These graphs were first presented in the source analysis section above, and are presented here for ease of reading this section.

It is clear from Figure 6.2 that maximum levels of nitrate occur at site 6.0. Recall that site 6.0 is immediately downstream of the WRF discharge; it is therefore reasonable that the highest levels occur downstream of this source.

6.1.1 Time

The graphs above indicate that the timing of loading and flow volume create a condition where maximum nitrate concentration occurs during late summer, i.e., when flow is at a minimum. The flow during this period, or *critical flow period*, can be used to calculate the TMDL. As nitrate concentration is inversely proportional to flow, and flow increases during winter months, implementing the TMDL based on the critical flow period will effect protection throughout the year.

6.1.2 Space

The graphs above also indicates that nitrate levels are highest at site 6.0 and 6.6. Recall that these sites are immediately downstream of both the WRF point source discharge and the confluence with Prefumo Creek. Together, the City's point source and the cropland source in Prefumo make up 85% total nitrate loading. It is reasonable that nutrient levels are at a maximum downstream of these sources. Therefore, achieving the capacity at site 6.0, i.e., based on the flow volume at this site, will effect protection at all other sites downstream.

6.1.3 Concerns Regarding Use of Critical Flow Period

Achieving the TMDL based upon the flow during the critical flow period (September and October) at site 6.0 will protect the stream from exceeding the numeric target during this time period at this site. The capacity (and therefore TMDL) of the stream during the critical flow period represents the maximum amount of loading that is allowed during *critical flow* while still being protective, yet also represents the resulting maximum concentration of nitrate that *will occur throughout the year*. Consequently, determining and implementing the TMDL based on the critical flow period will inherently assure that the TMDL will be achieved during other seasons as well. The following discussion addresses some concerns that may be raised due to this approach.

1. Design and implementation of a TMDL based on the critical flow period will underestimate allowable loading, while still being protective, during other seasons. Asking for a fixed reduction of loading based on this value could unnecessarily burden dischargers during wetter seasons.
    a. Explanation: 85% of the total nitrate loading is due to a single point and cropland source. The technological and management changes needed to meet the TMDL will be permanent in nature. This is particularly so for the Water Reclamation Facility.
    b. Explanation: As discussed in Section 3.4.2.3.1, the cropland source will be significantly mitigated through a land use change scheduled to begin in 2005.

2. Site 6.0 is nearly halfway up the main stem of the Creek, how can protecting site 6.0 protect upstream and downstream areas?
    a. Explanation: Sites upstream of monitoring site 6.0 have consistently been well below the proposed numeric target. Only main stem sites downstream of the point source and Prefumo Creek source regularly exceed the target. In addition, data clearly show that nitrate concentrations steadily decrease downstream of site 6.0.
    b. Explanation: There are no other significant nitrate sources downstream site 6.0 that will cause exceedence of the numeric target. In addition, all tributaries downstream of these sources are dry during the critical flow period, with the exception of San Miguelito Creek, which routinely discharges non-detect levels of nitrate.

Therefore, beneficial uses will be protected along all reaches of the Creek if the TMDL is calculated and achieved based on the critical flow period at monitoring site 6.0, located immediately downstream of the WRF discharge and confluence with Prefumo Creek. Upstream waters, i.e., upstream of site 6.0, will remain protected as these reaches currently meet the proposed numeric target.

6.2 Load Analysis During Critical Flow Period

Staff determined total nutrient loading and relative contribution by source during the critical flow period at site 6.0 (also referred to as SLOCK6.0, see map Figure 3.2). The following discussion explains the method for determining the nutrient loading during the critical flow period at site 6.0.

The nutrient load at site 6.0 was calculated by summing the loading from site 10.0, the WRF point source, and Prefumo Creek. Figure 6.3 below illustrates the location of these sites are in relation to each other. Flow and water quality data from staff monitoring, as well as the City's monitoring effort, were used. Total nitrate mass loading from each site was calculated for the months of September and October of 2001. An average of the two months loading was then determined. Therefore, the loading was determined as follows:

Mass load @ 6.0 = Σ [avg. Sept/Oct loads from (10.0, point source, Prefumo Cr.)]

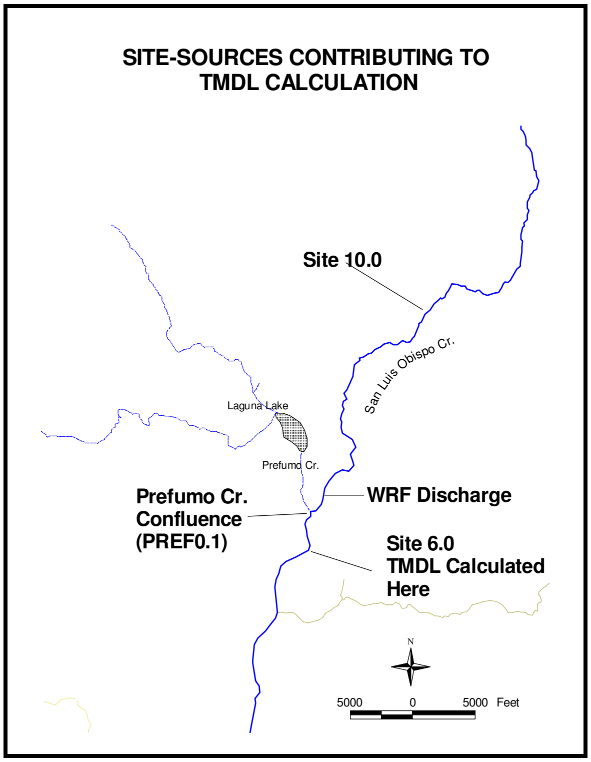

Figure 6.3 Monitoring sites used to calculate loading at site 6.0 during critical flow

Once the total load at site 6.0 during the critical flow period was calculated, the relative contribution of each source to this total load was determined. Staff utilized the percent contribution rates determined in the Source Analysis of Prefumo Creek subwatershed to determine contributions of various sources during the critical flow period in this subwatershed. To determine the relative contributions of the site 10.0 source, staff used the percent contribution rates determined in the Source Analysis of the Stenner Creek as well as main stem subwatersheds. The percent contributions for each source in these subwatersheds were averaged, and this average used to develop relative contributions during critical flow loading. The confined animal source is considered zero as the stream is dry in this area during the critical flow period. Please refer to Table 4.1 in the Source Analysis section for a description of contribution rate by source. Table 6.1 below shows mean flow, concentration, and loading from the sources upstream of site 6.0, as well as the resulting loading and flow at site 6.0.

Table 6.1 Mean flow, concentration, and loading at sites contributing to site 6.0 during critical flow period.

Mean Flow (ft^3/sec)			
Site	SEPT'01	OCT'01	MEAN
Site 10.0	No data	2.20	2.20
Point Source	5.72	6.35	6.04
PREF0.1	0.55	0.55	0.55

Mean Nitrate-N (mg/L)			
Site	SEPT'01	OCT'01	MEAN
Site 10.0	1.10	1.03	1.07
Point Source	19.73	16.13	17.93
PREF0.1	33.80	42.43	38.12

Mean Oct/Sept Nitrate-N Loading (lbs/mo)			
Site	SEPT'01	OCT'01	MEAN
Site 10.0		366.96	**367**
Point Source	18,220.44	16,515.37	**17,368**
PREF0.1	2,983.01	3,780.61	**3,382**

Loading and flow at site 6.0 is the sum of these sources		
Flow (ft^3/sec)	NO_3-N (lb/mo)	
8.79	21,117	

Note that total nitrate loading is calculated by summing the load for each month, then determining the average from these months; total load is *not* calculated from the mean concentrations and flows. Once the total nutrient load was determined for site 6.0, the load was distributed to the various sources using the loading rate developed in the Source Analysis. Table 6.2 below identifies loading during the critical flow period at site 6.0 by source.

Table 6.2 Relative and total loading by source at site 6.0 during critical flow

Source	**NO_3-N (lb/mo)**	**NO3 Relative Contribution (%)**
Background	8	0.04
Commercial/Urban	0.0	0.00
Cropland	3627	17.18
Confined animal	0	0
Reservoirs (lake)	112	0.53
Residential	2	0.01
Point Source	17,368	82.25
Total	21,117	100.00

Note that the nitrate loading to site 6.0 is 21,117 lb/mo during the critical flow period of September and October. The TMDL is calculated using the flow present at site 6.0, and the numeric target developed in the Numeric Target section.

6.3 Assimilative Capacity

The capacity of the Creek is calculated using the flow measured at site 6.0 using the model:

Mass = (concentration)(volume)(conversion factor)

Where: mass = M = lb/month (TMDL)
concentration = C = numeric target for NO_3 (10 mg/L-N)
volume = V = 8.79 ft^3/second
conversion factor = F = 161.38 (for conversion to lb/mo)

Therefore, the monthly assimilative capacity is determined by:

$$M = 161.38CV$$

Table 6.3 below identifies the calculations for the monthly TMDL for nitrate.

Table 6.3 Capacity calculations for site 6.0 during critical flow period

Calculation of Nitrate Capacity				
Nutrient	**F**	**C (target) (mg/L)**	**V ft^3/sec.**	**TMDL (lb/mo)**
NO_3-N	161.38	10.00	8.79	14,185

6.4 Wasteload Allocation, Load Allocation, and Margin of Safety

A general TMDL model includes a wasteload allocation (the point-sources), a load allocation (the non-point sources), and a margin of safety, as illustrated in the following equation:

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$

Where: TMDL is Total Maximum Daily Load, WLA is the waste load allocation, LA is the load allocation, and MOS is the margin of safety.

The TMDL equation then becomes (in monthly pounds of nitrate):

$$TMDL = \Sigma WLA + \Sigma LA + MOS$$
$$14{,}185 = 9{,}740 + 3{,}750 + 695$$

See accompanying spreadsheet: SLOnutTMDL, “Cap&Alloc” worksheet, cell AD29 for calculations.

In the case of San Luis Obispo Creek, the WLA is the allocation to the point-source from the City’s Water Reclamation Facility. The LA is the sum of the background, commercial/urban, cropland, reservoir, and residential sources. However, note that residential and commercial/urban sources are negligible (refer to Table 6.2).

6.4.1 Allocations

The allocations required to attain the TMDL are divided into the categories of wasteload allocations (WLA), referring to point sources, and load allocations (LA), referring to non-point sources.

Figure 6.5 illustrates the sites that will be referenced with respect to allocations.

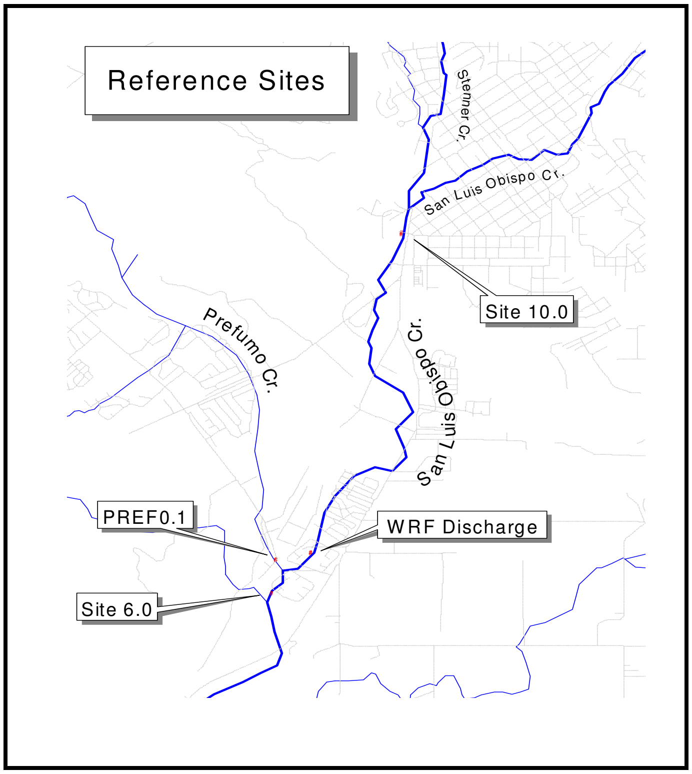

Figure 6.4 Reference Sites

The following are descriptions of the locations illustrated in the map above:

- Site 10.0: in San Luis Obispo Creek under Marsh Street bridge near the Highway 101 onramp.
- WRF Discharge: the outlet pipe discharging effluent from the City's Water Reclamation Facility.
- PREF0.1: Prefumo Creek under bridge crossing at Calle Joaquin Street,
- Site 6.0: San Luis Obispo Creek under bridge crossing Creek on Los Osos Valley Road.

6.4.1.1 Wasteload Allocation

The wasteload allocation is an allocation to the City of San Luis Obispo for the Water Reclamation Facility. The allocation is articulated as pounds of nitrate, expressed as N, allowed each month. The mass load allocation is calculated from the measured volume of effluent using the numeric target of 10 mg/L-N.

The waste load allocation for the WRF is:

9,740 lbs NO_3/month, measured as N.
In order to accomplish this the WRF effluent is not to exceed a nitrate concentration of 10 mg/L-N.

See accompanying spreadsheet: SLOnutTMDL, "Cap&Alloc" worksheet, cell AG24 for calculations.

Achieving this allocation alone will result in achieving the TMDL. This is so because the WRF contributes the largest proportion of total stream volume at site 6.0, relative to all sources of flow; the WRF contributes 69% of the flow compared to 6% contributed by Prefumo Creek.

6.4.1.2 Load Allocations

Load allocations refer to sources from background, cropland, commercial/urban, and residential. The allocations to these sources are equal to the current loading from these sources. Recall that this is so because site 10.0, upstream of the WRF discharge point, consistently carries nitrate levels well below the numeric target. Sources from Prefumo Creek watershed do not cause impairment in San Luis Obispo Creek. In addition, lower Prefumo Creek watershed will be undergoing development and therefore significantly mitigating nitrate loading from this watershed (refer to Section 3.4.2.3.1).

Therefore, the load allocations are as follows:

Background: **8 lbs NO_3/month, measured as N.**
Residential: 2 lbs NO_3/month, measured as N.
Reservoir: 112 lbs NO_3/month, measured as N.
Croplands: 3627 lbs NO_3/month, measured as N.
Total Load allocation is: 3749

See accompanying spreadsheet: SLOnutTMDL, "Cap&Alloc" worksheet, cell AC48 for calculations.

Note that the allocation to croplands is equal to the current loading. Also recall that reduction of nitrate from the cropland source is not needed to achieve the numeric target. Although a reduction is not needed from this source, it is expected that a significant reduction of nitrate loading will occur from this source. The reduction is expected because: 1) significant land use change from croplands to commercial in the lower Prefumo Creek watershed is expected, 2) remaining growers compliance with the agriculture waiver. As much as 50% of lands currently used for crop production in the lower Prefumo Creek watershed are expected to be converted to non-agriculture use. Growers remaining after the land use change will be required to obtain a waste discharger permit (which will require nitrate reduction), or obtain a waiver, referred to as an agriculture waiver. The agriculture waiver will require growers to reduce nitrate loading to a level where receiving waters carry nitrate concentration less than 10 mg/L-N, which is equal to the numeric target of this TMDL. Therefore, although nitrate reductions from the croplands source are not specifically mandated to achieve the TMDL, reductions are expected through growers compliance of the agriculture waiver, which in turn mandates an end numeric target equal to the numeric target used to develop this TMDL, as well as through land use change from croplands.

6.4.1.3 Margin of Safety

Section 303(d)(1)(C) of the Clean Water Act requires a margin of safety to account for uncertainties existing between the pollutant loads and resulting receiving water body water quality. This TMDL utilizes an implicit margin of safety to account for uncertainties. There is also a small explicit margin of safety.

The implicit margin of safety is built on the following conservative assumptions:

1. The TMDL is calculated for the critical flow period, which occurs in the late summer months. Numeric targets are, therefore, calculated based on a minimum dilution. Virtually all other periods during the year will have a higher dilution, relative to the critical flow period, resulting in nitrate concentrations lower than numeric targets.
2. A greater amount of dilution will occur during many future critical flow periods. The critical flow period is based on flow during the 2001-2002 rain year. However, rainfall during this period will be exceeded in 45% of subsequent years, based on 50 years of rainfall data. Consequently, base flow will be greater. In addition, tributaries in the lower reaches of the Creek will run longer into the year and contribute to dilution.
3. The Water Reclamation Facility (WRF) has plans and approval to implement a water reuse project (Project). The Project proposes to divert reclaimed water to users in the watershed. As much as 30% of the total annual discharge could be diverted, with 69% potentially being reused during the critical flow period. As such, a significant reduction in nitrate loading will occur, thereby reducing instream nitrate concentration to levels well below the projected target.
4. Uncertainty of unaccounted nutrient sources and loading is minimal. Recall that the WRF contributes over 82% of the nitrate delivered to the stream at site 6.0 during the critical flow period. The WRF is a regulated source and is operating under an NPDES permit. The WRF measures flow daily using a flow meter. Nutrient concentrations of the effluent are determined weekly. As a result, the TMDL calculation is based on accurate data, so the margin of uncertainty in the TMDL calculation is minimal. In addition, the uncertainty of future loading from this point source is minimal, as it is a regulated and monitored source.

In addition to the implicit margin of safety, an explicit margin of safety is also used. The explicit margin of safety is 695 lbs/nitrate per month, and is equivalent to 5% of the TMDL as mass.

7 Implementation Plan

7.1 Point Source

The WRF is required to reduce loading. The allocations will be required through the existing NPDES permit held by the WRF. The permit will be amended to include a nitrate allocation in the form of an effluent concentration limit for nitrate.

It is anticipated that a technological upgrade will be necessary for the WRF to meet the effluent limit. As such, a schedule will be required to allow the city of San Luis Obispo time to acquire funds and plans for the upgrade. The schedule will be articulated in the amended NPDES permit. Compliance and progress towards achieving the numeric target will be monitored through compliance with the schedule contained in the amended permit. It is expected that the upgrade will be online within the second permit cycle after the TMDL is approved, i.e., from five to ten years after TMDL approval.

7.1.1 Nonpoint Source Implementation

Achieving the TMDL implies that nitrate loading from nonpoint sources does not increase over current levels. Determining whether nitrate levels are not increasing from nonpoint sources will be accomplished by tracking compliance with existing regulatory mechanisms. No new regulatory mechanisms will be used.

Ensuring nitrate loading from cropland sources do not exceed current levels will be accomplished by monitoring required by the agricultural waiver. Ensuring nitrate loading from residential sources does not increase over current levels will be accomplished by monitoring compliance with existing stormwater permits. Table 7.1 shows the existing regulatory mechanisms and associated sources.

Table 7.1 Existing regulatory mechanisms to reduce nitrate loading

Source	Regulatory Mechanism(s)	Implementing Party	Implementing Action
Croplands	Agricultural Waiver	Growers in Prefumo Creek Watershed	Participation in agriculture waiver program
Residential	NPDES Stormwater Permit	Cal Poly State University, City of San Luis Obispo, County of San Luis Obispo	• Compliance with minimum measures of the permit, including: ❑ Public Education ❑ “Good Housekeeping” ❑ BMPs

7.2 Timeline and Milestones

Achieving the TMDL is dependent on the WRF achieving allocations. Therefore, milestone reductions will be realized only when technological based improvements are operating. It is expected that this will occur in the second permit cycle following adoption of the TMDL. It is therefore expected that the TMDL will be achieved on or before the year 2014.

7.3 Cost Estimate to Achieve TMDL

Achieving the TMDL will largely be accomplished by the reduction of nitrate mass loading from the WRF. It is expected that a technological upgrade will be necessary to achieve the allocations. The technological upgrade is expected to cost from 20-25 million dollars. The cost of the upgrade will be paid over a period of time through receipt of sewer charges imposed on the residents of the City of San Luis Obispo.

8 Monitoring Plan

Monitoring efforts are designed to gauge the impact of implementation actions on nitrate concentration in San Luis Obispo Creek. Monitoring will be conducted to:

1. Determine if and when the WRF has meet the allocation, and
2. Ensure that nonpoint sources of nitrate have not increased over current levels.

8.1 Monitoring Point Sources

Nitrate loading from the WRF will be done through staff review of progress reports submitted by the WRF. The NPDES held by the WRF will describe monitoring and reporting requirements. Regional Board still will utilize the WRF reports to:

1. Verify that the upgrade is progressing as described in the schedule, and
2. Monitor effluent and receiving water nitrate concentrations.

The NPDES permit will describe in detail the monitoring and reporting requirements of the WRF.

8.2 Monitoring Nonpoint Sources

Nitrate loading from nonpoint sources will be done through staff review of reports required through existing permits and waste discharge requirements.

Stormwater permits held by the city and county of San Luis Obispo and Cal Poly State University require minimum measures to control stormwater runoff. Annual reports are a requirement of the permits. Staff will utilize the annual reports to verify that minimum measures are in place. In addition, Cal Poly State University holds a waste discharge requirement (WDR). The annual report associated with the WDR will be used to confirm the requirements are being met.

The Agricultural Waiver requires monitoring and reporting. The reports generated from the waiver will be used by staff to verify compliance with the waiver, and therefore verification that nitrate loading from agricultural lands is not increasing.

9 Achieving the TMDL

Achievement of the TMDL will be based on receiving water nitrate concentration in San Luis Obispo Creek. Regional Board staff will review results of monitoring as well as reports associated with implementation actions (as discussed in the Implementation Plan). The TMDL will be considered achieved when the numeric target is consistently attained throughout the watershed, as verified by the weight of evidence presented to and/or obtained by the Regional Board. Evidence that the numeric target is consistently achieved includes, but is not limited to, implementation and monitoring reporting as outlined described, as well as any other evidence originating from entities other than those specifically articulated in this document.

Upon receipt of sufficient evidence suggesting that the numeric target has been and will continue to be achieved, Regional Board staff will recommend approval from the Regional Board that the TMDL has been achieved, and request that monitoring and implementation efforts be revised accordingly.

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11 Appendix

11.1 Review of Literature

USEPA identifies four approaches to establishing nutrient standards: 1) reference stream approach 2) predictive relationships 3) published thresholds 4) consideration of downstream receiving waters (USEPA, 2000). USEPA does not specifically address nutrient toxicity to wildlife as an approach. However, toxicity will be considered in this document.

11.1.1 Reference Stream Approach

The objective of the reference stream approach is to determine what the nutrient levels are in an undisturbed stream, and apply these levels to the target (impacted) stream. There are three basic methods for establishing nutrient criteria using the reference stream approach. The first two require a relatively large volume of data on many reference streams. The reference streams must have similar physical, chemical, and ecological features to the target stream; i.e., the reference streams and the target stream should be the same class of stream.

Objectives for the target stream are developed by locating key percentiles, e.g. the 75th percentile, of a frequency distribution of nutrient data gathered from the reference streams. For example, if a frequency distribution of nitrate concentrations were developed from reference stream data, the 75th percentile would be that concentration for which 75% of the reference streams had lower or equal nitrate concentrations. This nitrate concentration could then be used as an objective for the target stream.

This approach implies that: 1) there are a sufficient number of undisturbed streams of similar class to the target stream, 2) that data is available on a number of reference streams, and 3) that nutrient levels in non-impacted areas reflect levels for which no negative impact will occur. In regards to the first two implications, the availability of such data local to the target stream is often scarce. Consequently, agencies and managers may need to look regionally, and perhaps nationally, for reference stream data. The third implication is that nutrient levels need to be as low as one would find in pristine areas in order to protect beneficial uses. The fact may be that background nutrient levels protect beneficial uses, but this fact can not be used to deduce that levels must be at background concentrations, or lower, in order to reach the same level of protection.

As an example of this approach, data from hundreds of streams nationwide were compiled and used to create a frequency distribution of total nitrogen (TN) and total phosphorus (TP). Half the streams carried TN values greater than 0.9 mg/L, and half the streams carried TP levels greater than 0.04 mg/L (Dodds *et al*, 2000). These levels shed light on what levels in an undisturbed stream system should be, considering the USEPA finding discussed above that 50% of streams surveyed nationwide carried nitrogen levels above background levels (USEPA, 1998).

The third reference stream approach relies on best professional judgment. In this case, nutrient levels are assigned based on a small set of reference streams, or even one stream or reach, which according to best professional judgment reflects what the target stream levels would be in the absence of disturbance. This approach was used in a Montana stream using five years of data at six sample sites of a reference stream. The reference stream carried acceptable levels of algae. Total nitrogen levels of 318 µg/L (0.318 mg/L) and TP levels of 20.5 µg/L (0.0205 mg/L) were recommended as objectives to keep algae at acceptable densities (Dodds *et al*, 1997).

11.1.2 Predictive Approach

The second approach to developing nutrient objectives utilizes predictive relationships. Most predictive approaches attempt to discover correlation between nutrient and algal levels. The two methods discussed here are: 1) developing mathematical models to predict benthic algal levels, and 2) development of management strategies based on the trophic state of a stream system.

A brief discussion of algae is provided here to facilitate a full understanding of the predictive methods.

11.1.2.1 Algae

Algae include a large and diverse group of unicellular and multi-cellular aquatic plants. Some multicellular algae are attached to stream substrate, such as rocks, and are often referred to as benthic algae. Unicellular algae can be free-living organisms living in the water column, and are referred to as planktonic algae, or phytoplankton. As plants, algae utilize sunlight and carbon dioxide in the process of photosynthesis to produce oxygen and carbohydrates. Conversely, plants utilize oxygen in the evening during respiration for cell production. Consequently, aquatic systems rich with algae often experience high concentrations of dissolved oxygen during daylight hours, and depressed oxygen levels during the evening hours. Under certain conditions, depressed oxygen levels may temporarily fall below numeric objectives in place for the protection of aquatic organisms.

The benthic algae of concern in San Luis Obispo Creek is of the genus *Cladophora*, which attach to stream substrate in high-density colonies, consequently impacting stream ecology, chemistry, and aesthetics.

Cladophora glomerata is ubiquitous in stream systems (Dodds, 1991). *C. glomerata* is a filamentous green algae, forming branches up to several feet long and attaches to stream substrate. Growth is maximized in the following environment (Whitton, 1970) (Dodds, 1991):

- flowing water,
- high sunlight,
    - high sunlight favors branching; low light significantly reduces ability to fix CO_2,

- pH from 7-10, and not below 7.0,
- suitable substrate for attachment,
- calcium supply,
- magnesium supply.

Cladophora species experience high growth rates in early summer, followed by a period of low growth, then ending with another growth flush in early autumn. This phenomenon may be explained by the reproductive cycle of *Cladophora* .

Thick walled algal filaments remain on substrata through winter. As temperature and nutrient concentrations increase in early summer, conditions favor growth, after which peak densities occur. Some individuals produce and release zoospores, which in turn colonize on rock substrate and experience rapid growth. Colony densities then rise, peak, and level off in early autumn (Whitton, 1970). Winter rains cause increased stream flows, which often force detachment and removal of algal mats, leaving behind remnant filaments to serve as propagules for the following summer (Biggs, 2000). Once *Cladophora* is established, increased nutrient loading may not be necessary to maintain elevated algal densities (Chessman, *et al*, 1992). This cycle may indicate a potential lag-effect to control algae through nutrient reduction, as over-wintering filaments instigate new and rapid growth, and have lower nutrient requirements relative to growth via spores.

Cladophora species are native to many streams and play an important role in lotic system ecology. However, elevated densities of algae can impair stream ecology and human activity in streams. When densities causing impairments are reached, algae is present at nuisance densities.

Nuisance densities of algae impair stream ecology and can decrease recreational value of a stream. Large algal mats interfere with benthic ecology. It is the bottom of the stream where numerous invertebrate species play a vital role in the stream food web. A stream bottom free of nuisance levels of algae also provides habitat for fish during the sensitive embryo and larval stages. Dissolved oxygen, critical to many cold water species, can be significantly reduced by algae through respiration when densities are high or through decay after algal die-off. In addition, aquatic systems can be super-saturated with dissolved oxygen during daylight hours, and consequently play a role in producing harmful effects in fish.

Nuisance densities of benthic algae are quantified by average and maximum chlorophyll density in units of chlorophyll-a/m^2. Nuisance densities of benthic algae fall within the range of 100-200 mg/m^2 of chlorophyll-a (USEPA, 2000), with levels greater than 200 mg/m^2 of chlorophyll-a producing a very green stream bottom (Dodds *et al*, 2000).

Planktonic algae are microscopic organisms that, similar to benthic algae, also utilize photosynthesis. Planktonic algae are free-living in the water column, and as such do not pose a direct physical threat to the benthic stream community. However, because plankton rely on photosynthesis, nuisance levels are levels that adversely affect dissolved oxygen levels in the water column. Some planktonic algae may also release substances toxic to other aquatic species.

A unit of chlorophyll-a/m^3, or chlorophyll-a/L, is a unit used to quantify the density of phytoplankton. USEPA suggests a range of suspended chlorophyll-a in lakes and reservoirs of 0-24.6 µg/L, based on a database of reference conditions, with a level of 3.4 µg/L as a specific target associated with desirable dissolved oxygen levels. Suspended chlorophyll-a levels in streams and rivers should range from 1.78-4.85 µg/L, with a specific target of 1.78 µg/L being associated with desirable dissolved oxygen levels (USEPA[2], 2001). The state of Oregon has implemented a suspended chlorophyll-a target of 15 µg/L for lakes and rivers (DEQ, 2002).

11.1.2.2 Models and Experiments Predicting Benthic Algae

Extensive benthic algae mats are a visible sign of stream disturbance and as such have fueled research attempting to predict algal levels as a response to nutrient loading. The resulting mathematical models and analysis of data have had mixed results in this attempt.

For example, a question often posed is whether nitrogen or phosphorus is the limiting factor to algae growth. Of 158 separate bioassays studied, 13% confirmed that nitrogen was limiting, 18% that phosphorus was limiting, 44% that nitrogen and phosphorus together were limiting, and 25% that neither nitrogen or phosphorus were the limiting factor (Dodds *et al*, 2000). It therefore seems clear that the strategy for limiting algal growth will vary by stream.

The nutrient form used in mathematical models to predict algal density also varies. Some researchers achieved the highest correlation between algal density and nutrient concentrations using total nitrogen and total phosphorus (Dodds *et al*, 1997). (Examples of mathematical models and respective r^2 values will be outlined below). Other attempts to find best fit regression lines achieved maximum correlation to the data using dissolved inorganic nitrogen (DIN, or SIN) and soluble reactive phosphorus (SRP); using models based on DIN and SRP values may be particularly valuable if nutrient loading occurs via a point source delivering these forms (Biggs, 2000).

Antecedent nutrient and stream flow levels can also be used to predict algal growth. Considering nutrient levels 4-6 weeks prior to measured algal levels increased significance ($P<0.05$) between algal density and nutrient/flow parameters in a Montana study (Dodds, 1991). This phenomenon may reflect the ability of *Cladophora* to practice luxury consumption, where algal cells are capable of capturing and holding phosphorus in excess of growth requirements during phosphorus-rich periods, then utilizing the stored nutrient during periods when phosphorus is lean (Dodds *et* al, 2000).

The consideration of physical stream parameters to predict algae levels may also prove successful. Among the models reviewed for this document, highest correlation to data (r^2 0.741) was achieved by incorporating the parameter days of accrual (d_a) (Biggs, 2000).

D_a is the number of days since stream flow was three-times the median flow. Recall from the discussion above of algae reproduction that algal mats are removed during periods of increased flow. Mats typically re-emerge through growth of propagules left behind on substrate. Therefore, it seems logical that a relationship exists between the number of days since increased flow and algal density; i.e., that algal density is directly proportional to days of accrual.

Other models resulting in relatively high correlation (r^2 0.71) incorporate conductivity as a parameter (Chetelat *et al*, 1999). A best-fit line to the data was achieved using conductivity alone, and not incorporating particular nutrient levels. However, evidence does suggest that nutrients play a role in algal production. A nutrient poor stream in British Columbia, Canada, was spiked with nitrogen and phosphorus to promote primary production. The lack of primary production inhibited primary consumer populations, which in turn limited fish population. DIN and SRP levels were brought to 1000 and 100 μg/L, respectively, which in turn increased chlorophyll values from their initial level of <5 mg/m^2, to 150 mg/m^2 after nutrient loading (Perrin *et al*, 1987). The experiment shows a clear nutrient/algae relationship. Another significant point from this experiment is that algal growth reached a threshold, even as nutrient loading was being increased. This phenomenon of threshold density, or carrying capacity, is reflected in other studies as well (Pitcairn *et al*, 1973).

In a separate but supporting experiment, a stream carrying discharged effluent from a wastewater treatment plant supported algal levels downstream of the discharge significantly greater than densities upstream of the discharge. When phosphorus levels upstream of the discharge were artificially increased (from 0.25 to 1.6 mg/L), algal levels upstream increased an order of magnitude to levels not significantly different then those downstream (Pitcairn *et al*, 1973).

Recall from the discussion above that *Cladophora* does not efficiently synthesize CO_2 in the absence of high light; *Cladophora* is a shade intolerant plant. This point is made clear in an experiment located in Mendocino County, California. Artificial nutrient-diffusing substrata were placed in areas of open canopy and shade. Algal densities on substrata placed in shaded areas did not increase with nutrient enrichment, whereas substrata placed in areas of open canopy did (Hill *et al*, 1988).

Table 2.1 below summarizes mathematical models predicting benthic algae. All models outlined in Table 11.1 were developed from stream data where artificial or natural substrate were located in open canopy areas. The models are designed to predict mean chlorophyll-a values; where actual benthic chlorophyll values could be less than or greater than the predicted, or maximum chlorophyll values; where actual benthic chlorophyll values could be less than or equal to the predicted. Caution should be used when using the models to predict chlorophyll values outside the range of 5-300 mg/m^2, as this range was used to develop the models.

Table 11.1 Mathematical models predicting benthic algae*.

Equation	r^2	Reference
max log Chl-a = -2.946 + 4.285 log (d_a) -0.929 ($\log(d_a))^2$ + 0.504log(SIN)	0.741	Biggs, 2000
max log Chl-a = -2.714 + 4.716 log(d_a) -1.076 ($\log(d_a))^2$ + 0.494log(SRP)	0.721	Biggs, 2000
log Chl-a = 0.002 * conductivity + 1.134	0.710	Chetelat *et al*, 1999
max log Chl-a = -2.886 + 5.223 log(d_a) - 1.170 ($\log(d_a))^2$	0.618	Biggs, 2000
log Chl-a = 0.905 * log(TP) + 0.490	0.560	Chetelat *et al*, 1999
mean log Chl-a = -3.22360 + 2.82630 log(TN) - 0.431247 $(\log(TN))^2$ + 0.25464 log(TP)	0.430	Dodds *et al*, 1997
mean log Chl-a = -0.4285 + 0.92178 log(TP) - 0.16468 $(\log(TP))^2$ + 0.37408 log(TN)	0.429	Dodds *et al*, 1997
max log Chl-a = 0.00652 + 1.10067 log(TP) - 0.19286 $(\log(TP))^2$ + 0.3129 log (TN)	0.370	Dodds *et al*, 1997
max log Chl-a = 0.21620 + 1.47096 log (TP) - 0.22211 $(\log (TP))^2$ + 0.007238 (TN:TP)	0.368	Dodds *et al*, 1997

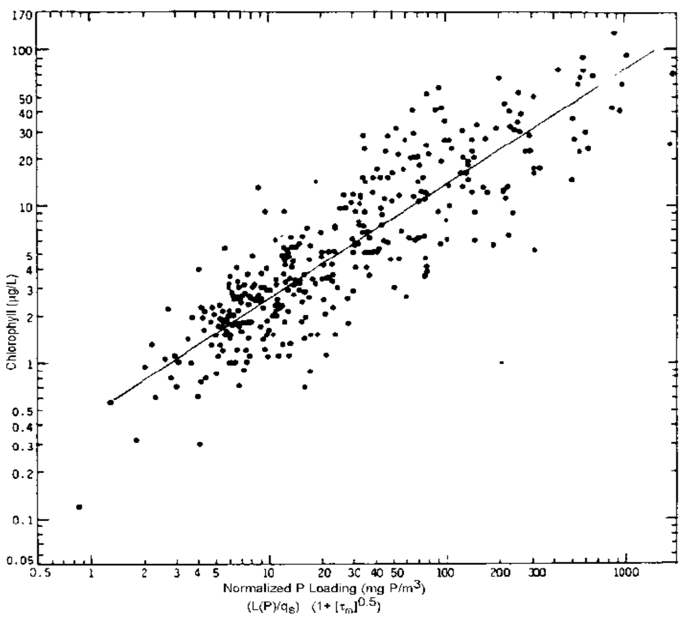
*Models presented were developed at sites with suitable substrate and solar radiation for algal growth.
Chl-a; Chlorophyll-a in mg/m^2
d_a; days of accrual; number of days since flow was 3X median flow
SIN; soluble inorganic nitrogen, µg/L
SRP; soluble reactive phosphorus, µg/L
TN; total nitrogen, µg/L
TP; total phosphorus, µg/L
TN:TP; ratio of total nitrogen to total phosphorus
conductivity; µS/cm

11.1.2.3 Planktonic Algae

The tactic often used to predict planktonic algae has centered on phosphorus concentrations. Both nitrogen and phosphorus are required for algal biomass production, with more nitrogen atoms needed relative to phosphorus. However, phosphorus is most often the nutrient limiting algal growth because it does not cycle in the environment as readily as nitrogen. Additionally, sunlight and other nutrients are needed for plankton growth. However, phosphorus can be controlled, and again, is often the nutrient in short supply. Consequently, a relationship between phosphorus loading and algal density (indicated by chlorophyll-a concentration) is used as a predictive model.

Research in this area often follows the work of Vollenweider, who in the 1960s began evaluating the relationship between chlorophyll-a and phosphorus levels in European waterbodies. Vollenweider found that surface area, hydraulic residence time (time for a waterbody takes to flush and refill), depth of the waterbody, and nutrient loading, play a role in planktonic algae levels, as indicated by chlorophyll-a concentrations. The Organization for Economic Cooperation and Development (OECD) funded a five-year study aimed at evaluating eutrophication as a response to nutrient loading in waterbodies in fourteen countries, including the United States. The OECD study confirmed and augmented the Vollenweider findings (Jones and Lee, 1986). Figure 11.1 below illustrates the updated Vollenweider-OECD regression.

Figure 11.1 Updated Vollenweider-OECD Regression



Updated Vollenweider-OECD normalized
P loading/chlorophyll response relationship

(from Jones and Lee, 1986)

The phosphorus loading is normalized with: P (mg/m^3) = (L/(P)/q$_s$)(1+[τ_ω]$^{0.5}$), where:

L(P) is aerial phosphorus loading, calculated as mass loading per aerial area of the waterbody (mg/m^2/yr),

- q_s is the mean depth per residence time (m/yr), and
- τ_ω is the residence time of the water (yrs).

The equation above is used to predict the amount of phosphorus available to algae after losses, such as settling. As can be seen from the equation, the available phosphorus is inversely proportional to mean depth. Therefore, shallow waterbodies will have a greater proportion of the loaded phosphorus available to algae, relative to deeper waterbodies. Hydraulic residence, or the residence time of the water-volume is also considered, and is directly proportional to chlorophyll-a, and consequently planktonic algae.

Using these variables, waterbodies of various sizes, depths, and hydrologic regimes can be evaluated with the model. For example, a target phosphorus concentration can be developed if a target chlorophyll-a value is established.

11.1.3 Published Thresholds Approach

Utilizing published thresholds is the third approach of developing nutrient criteria. Some agencies and managers have implemented management actions and thresholds that can be used as a basis by other agencies and projects. Table 11.2 below outlines some published thresholds. Thresholds intended for lakes and reservoirs is included because a portion of lower San Luis Obispo Creek (discussed below) has attributes similar to that of reservoirs.

Note the range of values in Table 11.2 recommended for protection. The ranges reflect not only the differences in methods and results of research, but also the risk for which the thresholds are designed to protect.

Table 11.2 Published thresholds

Protection	TN	TP	DIN	SRP	Chlorophyll-a	Source
	µg/L	µg/L	µg/L	µg/L	see note	
Human toxicity			10,000[1]			from Dodds *et al*, 2000
Mean chlorophyll-a < 50 mg/m^2	470	55				from Dodds et al, 2000
Mean chlorophyll-a < 50 mg/m^2	250	21				from Dodds et al, 2000
Max. chlorophyll-a < 200 mg/m^2	300	415				from Dodds et al, 2000
Sig. effect to inverts.& fish		170	1370			from Dodds et al, 2000
Max. chl < 200 mg/m^2 @ d_a=50			19	2		from Dodds et al, 2000
Periphyton and macrophyte control			1000	20		from Dodds et al, 2000
Chl 100-200 mg/m2	275-650	38-90				from USEPA, 2000
Chl < 200 mg/m2	1500	75				from USEPA, 2000
Cladophora nuisance growth		20				from USEPA, 2000
Cladophora nuisance growth		10-20				from USEPA, 2000
Eutrophic conditions			430	60		from USEPA, 2000
Reduced invertebrate diversity (Chl<100 mg/m2)			25	3		from USEPA, 2000
Benthic algae at nuisance level					100-200 mg/m^2	USEPA, 2000, and Dodds et al, 2000
Phytoplankton bloom in lakes, reservoirs					0-24.6 µg/L	$USEPA_2$, 2001
Phytoplankton bloom in lakes and reservoirs					3.4 µg/L	$USEPA_2$, 2001
Phytoplankton bloom in lakes and reservoirs					15 µg/L	DEQ, 2002
Phytoplankton bloom in streams, rivers					1.78-4.85 µg/m^3	$USEPA_2$, 2001
Phytoplankton bloom in streams, rivers					1.78 µg/m^3	$USEPA_2$, 2001

1; NO_3-N

Chlorophyll-a; chlorphyll-a
d_a; days of accrual; number of days since flow was 3X mean flow
inverts.; benthic invertebrates

Note the recommended suspended chlorophyll-a values in Table 11.2; these values can be used to in combination with the Vollenweider model to develop phosphorus values.

11.1.4 Consideration of Downstream Receiving Waters Approach

The fourth, and final, approach for developing nutrient criteria is the consideration of downstream receiving waters. USEPA refers to controlling the effects of nutrient loading in lakes and estuaries in this approach. Of particular concern is the conversion of a lake or estuary to a eutrophic state, and the consequences of such a conversion. Consequently, a great deal of research and data has been produced aimed at predicting algal densities in waterbodies as a response to nutrient loading.

11.1.5 Toxicity Approach

USEPA does not specifically consider toxicity as an approach to developing nutrient criteria. However, the potential that elevated levels of nutrients are toxic to aquatic organisms must be addressed, as nutrient loading attributed to anthropogenic sources have increased receiving water concentrations three orders of magnitude above background levels in some areas (see Source Analysis section for data).

Unfortunately, information on the toxicity of nutrients to lotic organisms is not as voluminous as information regarding nutrient/algal relationships. Information is limited on the number of species for which toxicity tests have been conducted, as well as the number of developmental stages investigated. Research pertaining to the latter is warranted as data suggests that early stages of fish and amphibian species are more susceptible to nutrient increases than their adult counterparts (Rouse *et al*, 1999).

It is widely accepted that amphibian populations are in decline, which has fueled research in this area (Drost *et al*, 1996). Data noteworthy to this project include nitrate toxicity to frogs and toads. Declining fish populations and federal listings of some species has also fueled research. These events have lead scientists to consider habitat loss, predation due to introduced species, and degraded water quality as potential causes. Threat to water quality has led some investigation into sources due to agricultural activities. One reason for this approach is that amphibian decline in California is significantly greater in areas adjacent agricultural land use, relative to other land uses (Fisher, 1996).

11.1.5.1 Methods of Reporting Toxicity

Nitrate toxicity is reported in various ways. Some research has resulted in lethal concentration limits (LC) being established. The LC limits are reported as the exposure time resulting in a specified percent of individuals dying. For example, a 120-hour LC_{50} of 18.3 mg/L NO_3-N implies that 50% of the individuals died after 120 hours of exposure to 18.3 mg/L of NO_3-N.

Another approach to expressing toxicity is the reporting of the lowest concentration that results in a statistically significant adverse effect, referred to as the lowest observed adverse effect level (LOAEL). The LOAEL is reported with the time of exposure, dose, and adverse effect. For example, a 16-day LOAEL of 8.9 mg/L NO_3-N implies that a 16-day exposure of 8.9 mg/L NO_3-N had an adverse effect on the organism tested. The adverse effect may be specified as reduced weight, length, development, etc.

A predictive approach can be taken by utilizing LOAEL data. A range of LOAEL levels were regressed against adverse effects to *Bufo americanas* (American toad) and *Rana pipiens* (Leopard frog). The regression produced a trend showing that nitrate concentrations from 0-50 mg/L NO_3-N are correlated with declining tadpole weight (r^2=0.73) (Hecnar, 1995). Reduced size is significant to survival as smaller individuals are more susceptible to predation (Baker *et al*, 1994).

11.1.5.2 Toxicity and Management Considerations

Nutrient toxicity data is limited on frog, toad, and fish species. Therefore, managers are left with the following considerations:

- lethal concentrations;
    - what percent mortality is acceptable?
    - would an exposure-duration longer than the tested exposure time (for which no mortality was noted) cause mortality?
- least observable adverse effect levels;
    - if an LOAEL test did not yield significant results, could longer exposure with lower doses yield significant adverse effects?
    - could extended exposure at lower doses to parents result in adverse effects to offspring?
    - are there adverse effects not being considered?
- Species;
    - if data is lacking for a species present at a project site, should managers consider toxicity data at the genus level, or should only species-specific data be considered?

11.1.5.3 Levels of Toxicity

Table 11.3 below outlines nitrate toxicity levels to some aquatic species. The list is not exhaustive; it includes dose levels and species of interest to this project.

Table 11.3 Nitrate toxicity by species

Species Common	Species Scientific	Risk Level NO3-N (mg/L)	Effect	Reference
Steelhead trout	*Oncorhynchus mykiss*	1.1	egg mortality significant over control	Kincheloe *et al*, 1979
Rainbow trout	*Oncorhynchus mykiss*	2.3	egg mortality significant over control	Kincheloe *et al*, 1979
Brook trout	*Salvelinus fontinalis*	6.25	100-day LOAEL; embryo mortality, growth	Crunkilton, 2000
Common toad	*Bufo bufo*	8.9	14-16-day LOAEL; embryo reduced length	Baker *et al*, 1993
Whites tree frog	*Litoria caerulea*	8.9	16-day LOAEL; embryo length and mortality	Baker *et al*, 1994
Chorus frog	*Pseudacris triseriata*	10.0	100-day LOAEL; fewer morphs	Hecnar, 1995
Eastern American toad	*Bufo americanus*	13.6	96-hour LC_{50}; embryo	Hecnar, 1995
Caddisfly	*Hydropsyche occidentalis*	18.3	120-hour LC_{10}	Camargo *et al*, 1992
Red-legged frog	*Rana aurora*	<29.1*	16-day LOAEL; embryo reduced length	Schuytema *et al*, 1999

* lowest concentration used in study; minimum adverse effect level could be lower

Note from Table 11.3 that the lowest nitrate toxicity level is 1.1 mg/L NO_3-N, producing adverse effects to steelhead tout. No replication of the 1979 study could be found for this project.

Supersaturation of dissolved gasses in water are potentially be toxic to fish. Nuisance levels of algae can affect dissolved oxygen (DO) levels. Specifically, DO levels can be reduced below thresholds needed by some fish. Consequently, agencies most often set DO targets as minimum levels, representing levels for which DO should not fall *below*. However, elevated algae levels can also cause supersaturation of dissolved oxygen, particularly during hours of peak solar radiation. Under supersaturated conditions, DO levels exceed 100% saturation. Water quality objectives seldom address supersaturation, i.e., a level *above* which DO should not rise. However, evidence suggests that supersaturation of dissolved oxygen can be deleterious to fish.

Gas bubble trauma (GBT) is a disease affecting fish and potentially other aquatic organisms. Waters supersaturated with dissolved gas can cause gas bubbles in the eyes and fins of fish, interrupting blood flow and eventually causing death. Research into GBT was first prompted by gas supersaturation caused by hydroelectric dams, as water flowing through spillways and turbines can create supersaturated conditions immediately below the dam as well as in downstream waters. Atmospheric gasses are dissolved in water as flow moves through turbines and spillways. Most of the gas imparted through the process is nitrogen and oxygen gas. Total dissolved gas (TDG) is a measurement of the ratio of the combined nitrogen and oxygen gas pressures to atmospheric pressure.

The TDG threshold level for *Oncorhynchus mykiss* (steelhead and rainbow trout), i.e., that level below which GBT does not occur, and above which GBT does occur, is 116% TDG (Nebeker and Brett, 1976). *O. mykiss* exposed to 120% TDG suffer both chronic and acute affects with death occurring in some individuals, and at 130% saturation, death results in most individuals tested (Mesa *et al*, 2000) (Abernathy *et al*, 2001) (Nebeker and Brett, 1976). Table 11.4 below illustrates the risk level associated to steelhead trout at differing saturation levels and exposure times.

Table 11.4 Mortality to steelhead trout at differing TDG levels

TDG (%)	Exposure time (hrs)	Mortality (%)	Source	Notes
120	16-22	14	Abernathy *et al*, 2001	
120	20-30	20	Mesa *et al*, 2000	
120	30	20	Nebeker and Brett, 1976	
120	43	50	Nebeker and Brett, 1976	
130	5-7	20	Mesa *et al*, 2000	
135	2	<50	Abernathy *et al*, 2001	began convulsing and dying within 2 hrs
135	5	>50	Abernathy *et al*, 2001	most died within 5 hrs
135	16-22	100	Abernathy *et al*, 2001	

Note in Table 11.4 that at 135% TDG death begins occurring in some individuals within 2 hours, and most are dead within 5 hours. It is apparent that steelhead are negatively affected at 120% TDG as well.

11.2 Statistical Results: Mann-Whitney Tests

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Mann-Whitney Test and CI: site10.0, site10.3

```
site10.0   N =  16     Median =      0.9500
site10.3   N =  12     Median =      0.0750
Point estimate for ETA1-ETA2 is      0.8000
95.2 Percent CI for ETA1-ETA2 is (0.6500,1.0500)
W = 328.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

Mann-Whitney Test and CI: site6.6, site10.0

```
site6.6    N =  18     Median =      15.150
site10.0   N =  16     Median =       0.950
Point estimate for ETA1-ETA2 is      14.200
95.3 Percent CI for ETA1-ETA2 is (7.298,17.999)
W = 459.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

Mann-Whitney Test and CI: site6.0, site6.6

```
site6.0    N =  13     Median =      19.300
site6.6    N =  18     Median =      15.150
Point estimate for ETA1-ETA2 is       4.650
95.2 Percent CI for ETA1-ETA2 is (-0.103,11.000)
W = 254.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.0328
The test is significant at 0.0326 (adjusted for ties)
```

Mann-Whitney Test and CI: site1.9, site2.5

```
site1.9    N =  10     Median =      13.300
site2.5    N =   7     Median =      11.800
Point estimate for ETA1-ETA2 is       0.500
95.5 Percent CI for ETA1-ETA2 is (-3.500,7.496)
W = 91.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.4611
The test is significant at 0.4611 (adjusted for ties)

Cannot reject at alpha = 0.05
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